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SUGAR-CANE GROWTH MEASUREMENTS IN BARBADOS

By

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SUGAR-CANE GROWTH MEASUREMENTS IN BARBADOS.

I. INTRODUCTION.

Sugar-cane growth measurements were started in order to ascertain to what extent it is possible to determine the reasons for the economic adaptability of different varieties to different environments in this manner. The methods employed were such as to note, for chosen varieties, the seasonal trend of certain growth expressions in aboveground parts under different environments.

The practical experience of generations of planters has indicated that in so small a sugar-cane growing area as Barbados, different varieties are best suited economically to different parts of the Island. Experiments run by the Department of Science and Agriculture for the last four years have definitely confirmed this. There is the well known example of the two varieties, B.H. 10(12) and Ba. 11569. The former is the commercial variety in the higher-rainfall district in the Island, but is relatively a failure in the lower-rainfall district. The converse is the case with Ba. 11569. Numerous other cases of the economic suitability of different varieties to environments could be given from the more recent Barbados seedlings, but the above standard varieties of long standing are cited as a definite and well known example.

In the work of producing and selecting seedlings, varieties of different adaptabilities are encountered. The selection of parent varieties and seedlings by the plant breeder would be greatly facilitated if growth investigations revealed the existence of readily recognisable growth-types most likely to succeed in certain environments. This would facilitate the selection of seedlings and their allocation for trial in their most suited environments.

The growth-measurement studies here detailed, definitely suggest that such a method is possible.

Preliminary growth measurements in sugar-cane varieties in Barbados were commenced during 1928. These led to the adoption of methods for growth studies during 1929, 1930 and 1931. During those years, growth was measured by obtaining periodic data on tiller production, tiller deaths and growth increments in cane. In 1932 a further expansion of the growth investigations was made to include data on cane production.

The findings from the measurements have given, besides particular varietal-growth information, certain indications as to the general effect of environment on sugar-cane growth, which may be of use in practical sugar-cane agriculture.

It is hoped, in the near future, to amplify the information recorded here by further growth measurements in plant canes and in ratoons and by root-system and underground-branching studies.

II. METHODS.

(1) Measurements of Growth.

All measurements were made in varieties included in maturity experiments. Reports on these latter have appeared from time to time in recent publications of the Department of Science and Agriculture, so that their objects need not be detailed here.

During any one planting season, two similar "maturity" experiments were planted; one on an estate in the lower-rainfall black coral limestone district, the other on an estate in the higher-rainfall red coral limestone district; these sites being chosen to determine the effects of different environments on growth. Each variety, at each place, was placed at random in each of twenty-four blocks. During 1929, 1930 and 1931, twenty stools were measured for each variety—two stools in each of ten contiguous blocks. In 1932, thirty stools of each variety were measured—nine in each of three contiguous blocks, and three in a fourth contiguous block. Measurements were not made in poorly developed stools. (The sugar-cane crop in Barbados is grown on the cane-hole system. At the higher-rainfall station these holes are spaced 5′ x 5′, at the lower-rainfall station, 6′ x 6′).

Eight series of measurements was started towards the end of March, and continued over fortnightly periods until December of the same year or January of the succeeding year; that is, from when the crop is about four months old, (having already developed slowly during three low-rainfall months) until approximately one month before the start of harvesting.

During 1929, 1930 and 1931, tiller production, tiller deaths and cane growth increments were noted for each fortnightly period. Canes were not considered as distinct from tillers. In 1932, a distinction was made between tillers and canes. A tiller was considered to have become a cane when it was observed, on stripping the lower leaf sheaths, to possess a minimum of two well-defined "cane-like" nodes. This distinction is one in name only, for the tiller is the precursor of its own cane—if development should proceed sufficiently. This distinction has given useful information about the all-important feature—cane formation.

Cane-growth measurements were made by the method of Kamerling (Barber, Studies No. 5). One average-sized tiller was selected in each stool and measured at the stated intervals from ground-level to the base of the last visible leaf-triangle. Whenever the vegetative growth of a measured cane was interrupted by any abnormal factor, a change was made to a cane of approximately similar appearance in the same stool, and the necessary arithmetical adjustments made in determining the increments.

The figures for each measured feature in every variety at each measurement, at both stations, were obtained by averaging all the twenty or thirty measurements; and the changes between fortnightly periods were noted by the differences between such means.

Thus, for each variety, for the two stations, a history of the external changes in its important above-ground features was obtained for the greater part of one or more growing seasons.

The varieties measured, with their years of measurement, were:—

1929—B.H.10(12), Ba.11569, B.726, B.417, Ba.6032, B.465.

1930—B.H.10(12), Ba.11569, B.726, B.417, B.374, B.605, P.O.J.2725 and P.O.J.36.

1931—B.H.10(12), Ba.11569, B.726, B.417, B.891, Co.213.

1932—B.H.10(12), Ba.11569, B.726, B.891, B.2935, P.O.J.2878.

Thus, B.H.10(12), Ba.11569 and B.726 were measured for four seasons, B.417 for three, B.891 for two, and the others for one each.

(2) Measurements of Environment.

The Soil. The nature of the black (lower-rainfall district) and red (higher-rainfall district) coral limestone soils has been investigated by Saint, whose findings have been used in their descriptions.

Nutrition. The manurings of the fields in which the experiments were laid out, were furnished by the managers of the plantations concerned in the course of ordinary plantation practice.

Soil-Moisture. In 1929, fortnightly estimates were made of the water-supplying power of the soils at both stations, by the pencil-point method of Hardy. The principal object of this was to note whether there tended to be any accumulation of moisture in the upper root-supporting soil layers as the rainy season progressed. This method, when accurately done, considerably increased the work. From the data, to be presented later, it is seen that, during the measuring season, when temperatures are high, efficient growth is only recorded if the rainfall of approximately the last four weeks has been adequate. The soil water-supplying powers of each period were, therefore, related to the rainfall of the period and that preceding it; and the estimation of the soil water-supplying power discontinued after 1929.

Soil Temperature. Soil-temperature readings were made by means of Negretti and Zambra Earth Temperature Recorders. A bulb was inserted at the base of a stool in the middle of each growth-measurement area. During 1930 and 1931, the bulb at each place was placed at varying depths. At a depth of twelve inches the temperature charts revealed approximately straight lines.

Daily soil-temperature fluctuations increased as the bulbs were inserted progressively nearer the surface. Throughout 1932, the bulbs were placed at a depth of four inches. This depth was chosen, since several investigators on root-system development in sugar-cane have found that the greatest development of roots takes place in the top eight to ten inches of soil. It was considered, therefore, that readings at four-inch depths would represent approximately the temperatures in the region of the greater part of the absorbing root-system.

Air Temperature. Air temperatures were obtained on Townson and Mercer's Air Temperature Recorders. These were placed in a double screen at a height of five feet, in the middle of each growth-measurement area.

Air Humidities. Air Humidities were recorded on Negretti and Zambra Recording Hair Hygrometers in the same screens. The actual recordings were periodically found to be unreliable, and frequent calibrations had to be made. As a result, no direct air humidity comparisons could safely be made between the two places. The readings were, however, useful for considering the daily fluctuations in relative percentages air saturation.

Rainfall. This was recorded in rain gauges in the yards of the estates on whose fields the experiments were laid out. Returns of the day and night rainfalls were made throughout the years.

Wind Velocity. Wind velocities were taken on a Robinson Cup Anemometer at Codrington Experiment Station, which is situated about eight miles from the sites of the measurements.

Sunshine Records. Sunshine records were taken on Campbell-Stokes Pattern Sunshine Recorders. Those at Codrington Experiment Station served for the lower-rainfall station, while those from Lion Castle plantation served for the higher-rainfall station. The latter is about one and-a-half miles from Lion Castle.

No evaporation records were obtained, and evaporation intensities at both places can only be suggested through consideration of the other climatic factors.

III. PRESENTATION OF THE DATA.*

(1) The Environment.

The Soil. The lower-rainfall station (Graeme Hall) is situated in the black coral limestone soils, and the higher-rainfall station (Vaucluse) in the red coral limestone soils. These two soil-types constitute approximately 90% of the soils in the Island. Both types overlie the coral limestone rock (from which they are derived) to a depth of approximately two to three feet. They fall under the loam classification. They contain a high percentage of clay, but retain an excellent texture due to their being fully saturated with lime. They drain readily and it is thought that the underlying coral rock may serve to act

* For purposes of economy, several graphs illustrating features of the climate have been omitted. The salient points derived from such graphs are, however, noted in the text.

as a storehouse of moisture which serves to tide the sugar-cane over prolonged periods of severe drought. The pH values vary in samples from pH 7.6-8.5. They are low in humus content. Both colour types have very similar mechanical analyses and index-of-texture figures. "It has been found that the clay fraction "of the black soils has a higher silica/alumina ratio than the clay fraction from "the red soils. This lower ratio in the red soils possibly accounts for the lower "absorbing power of the red soils when compared with the black soils of similar "mechanical analyses." The red soils are more easily worked after rain than the black soils and they are more quickly affected by drought. It is thought probable, in view of the above, and also from the nature of fluctuations in soil temperature, that water moves more quickly in the red than in the black soils.

On the whole it appears that these soils differ only slightly in their intrinsic capacities to promote growth.

Nutrition. Saint has shown that there is no response by sugar-cane to phosphatic manuring in these soils, and that there is little likelihood of any deficiency of nitrogen or potash under the existing plantation manurial practices.

At both stations a more than adequate supply of nitrogen and potash was given in the form of pen-manure during the land preparation period just prior to planting. At Vaucluse, about 150 lb. of fish manure was applied per acre in January. At both places, 112 lb. per acre of nitrate of potash was supplied in January, February or March. Again at both places, in all seasons considered here, sulphate of ammonia was applied at the rate of about 220 lb. per acre at the beginning of the rains (about June or July in any year).

The recent tendency in manuring in the Island has been to adopt a recommended rational system, whereby the amounts of essential elements are curtailed so as to be more in keeping with the cane tonnages likely to be obtained under the existing rainfall.

It can be stated with a fair degree of confidence that the nutrition available during the four seasons under review, was at no time a limiting factor to growth.

Soil Temperature. Graphs of soil temperatures at 4″ and 12″ depths are shown in Fig I.

The soil temperatures show a daily periodicity which is correlated with that of the air temperatures. At 4″ depth there is a lag of three hours, at 12″ depth the lag is eight hours, behind the air temperatures.

The range between the maxima and minima at 4″ is considerably less than the air temperature range, but is much greater than the range at 12″. The range at the latter depth is almost negligible.

The graphs show high temperatures during May to September, with dropping soil temperatures from mid-October through November and December. This drop is seen in the soil temperatures at both depths. The soil temperatures

at Graeme Hall (lower-rainfall station) exceed those at Vaucluse (higher-rainfall Station) by about three degrees.

Air Temperature. Air temperature records at Codrington Experiment Station show that mean monthly ranges tend to be similar (Fig. II.) Temperatures are lowest in January and February, then rise through March, April and May. High temperatures are sustained throughout June, July, August and September. Temperatures then diminish progressively through October, November and December. The December means are only little higher than those for January.

The mean monthly maxima and minima for 1929, 1930, 1931 and 1932 show that there is little deviation from the means of the monthly means from 1903 to 1928.

Appreciable departures are seen in the mean maxima during August and September, 1930, and during the dry season of 1931. On both occasions moisture was a limiting factor to efficient growth, so that such departures cannot of themselves have had any appreciable effect on growth.

The fortnightly mean maxima and minima for 1930, 1931 and 1932 at Graeme Hall and Vaucluse show that the general seasonal march of temperatures tends to be alike at both places and resembles those for Codrington Experiment Station. The actual means, however, show the Graeme Hall temperatures to be on the average about three degrees higher than those at Vaucluse.

The progressive drops in temperature through November, December and January are very marked. The possible effect of this on the growth of the old crop is discussed later.

It is significant that during the greater part of the rainy-season months, temperatures run high.

Rainfall. Of all factors which influence sugar-cane growth in Barbados, rainfall is by far the most important. This may be due to several causes: (1) it being of itself the only recognised acute limiting factor to sugar-cane growth in Barbados, (2) its great variability in amount and distribution from year to year and from place to place, and (3) its influence on humidity, temperatures (air and soil) and so evaporation, transpiration and absorption.

The average monthly precipitation from 1903 to 1928 at Codrington Experiment Station* demonstrates the seasonal distribution. The months January to May, inclusive, have very low rainfalls. Precipitations increase through June and August. On the average, high rains occur during August, September, October and November, but are less during December.

With the possible exception of October and, to a lesser extent, November, the months show great deviations from the average. Thus, although the June,

* This station is situated in the lower-rainfall black coral limestone district

July and, more particularly, the August and September rains are, on the average, high, their extents tend to vary greatly from year to year, so that unfortunate dry spells are liable to occur during these months.

The rainfall graphs for the two stations, during the years of measurement, are shown (Figs. III and IV). These indicate the high variation in amount and distribution from year to year, and also the difference between the amounts at both places in each year.

Air Humidities. These are important in so far as they affect evaporation and transpiration.

The daily periodicities at both places are similar and well marked. The effect of rains is to disturb this daily periodicity so that higher humidities are recorded during those hours which the rainfall affects, but there is a tendency for the normal percentage saturation figures to be restored, so soon as the saturation effects of the rains have disappeared. This restoration is surprisingly rapid, except during successive days of cloud and rain which may occur particularly during October and November.

The atmospheric humidities at both stations do not differ to any appreciable extent, and they are chiefly referable to more frequent rains at the rainier station.

Martin Leake considers that:—"Under the climatic conditions prevalent "in a rains track, there is a close association between rainfall and humidity. "The effect of air humidity as a separate independent factor may, therefore, be "disregarded."

It appears that the rainfall differences at both places and in different seasons is an indication of humidity departures from the dry weather daily rhythm, and thus the effect of the humidity factor in so far as it affects evaporation and transpiration, and so growth differences between places and seasons may be referred to differences in rainfall amounts and distributions.

Wind Velocity. Day and night wind-velocity figures are noted throughout the years at Codrington Experiment Station. It is considered that the wind velocities at that station are a fairly close approximation to those in the exposed fields where growth measurements were made. These figures are used to give indications of the wind velocities at both places.

The points on the graphs (Fig. V) are the means of the calendar months. The means of the monthly means from 1903 to 1928 show that the wind velocities are considerable during the dry-season months, January to April, and that they rise slightly during May and are highest in June and July. They drop considerably in August and are lowest during the rainy season months of September, October and November, but rise slightly during December. There are many still days and nights during August, September, October and November.

The mean monthly maxima and minima graphs over these years show that the ranges from the monthly means referred to previously, are greater during February to July, inclusive, than during August to January, inclusive.

The days are almost invariably windier than the nights.

The graphs for 1929, 1930, 1931 and 1932 show that, although these years are less windy than the averages for 1903 to 1928, the general monthly distributions are a fair approximation to them. The year 1931 deviates somewhat, in that the winds in the dry-season months are lower than usual, while those of the rainy-season months are higher, with the result that the graph has no great range over the year.

There is, however, a remarkable constancy in the monthly averages, ranges and distributions from year to year. This leads to the conclusion that wind velocity, as far as it is a factor affecting evaporation and transpiration, plays little part in any growth differences between years. Its chief importance lies in its effect on the moisture relationships throughout the course of each year.

Sunshine Records. The data for Codrington Experiment Station—to serve for the lower-rainfall station, Graeme Hall—shows (Fig. VI) that for yearly sunshine distribution, with the exception of 1930, which was a sunny year of very low rainfall, the monthly sunshine records are very close. The hours of sunshine are seen to be high during the dry season, from January to June. They are less during July, August and September, and least of all in October and November. They increase suddenly in December and are again high in January.

The Lion Castle records—to serve for the higher-rainfall station, Vaucluse —although incomplete, suggest that the yearly distributions and actual amounts are very closely related to those at Codrington Experiment Station.

Length of Day. Days are shortest in December and January—about eleven hours—increase to their longest in June—about thirteen hours—and shorten again to December. There is approximately a difference of two hours between the longest and the shortest days.

Summary of Meteorological Data of the Environment.

The graphs illustrating the climatic factors of the environment, and the notes on each in the text, indicate that there are well defined climatic periods during each year. Each of these periods is recognised as having distinct general effects on sugar-cane growth.

With the exception of rainfall and its interdependent variable humidity, there is seen to be a close approximation of these factors from year to year. It is therefore unlikely that they would, to any extent, be the cause of differences in growth between years.

Place differences—as illustrated by a comparison of the two stations considered—lie essentially in rainfall differences, and, to a lesser extent, in actual temperatures. The independent effect on growth of these differences in temperature cannot be evaluated from the measurements, but it is considered to be almost negligible when compared with the effect of the differences in rainfall.

In conclusion, it is considered that the well-recognised climatic periods occurring during each year, affect the general trend of growth and that the rainfall differences from year to year and between place and place are chiefly responsible in promoting the yearly and place growth-differences.

The importance of soil moisture—here referable to rainfall—to growth is thus recognised.

Its effect is, therefore, particularly stressed in the subsequent sections.

(2). Growth Measurements.

These are considered under the headings:—

(1) tiller production,
(2) tiller deaths,
(3) cane production, and
(4) cane length-increments.

These are all measurable quantities, and the figures for each are presented in a series of graphs for both places, over one to four measuring seasons, as the means of the same three variety means established for fortnightly measuring periods (Figs. VII-XV).

The flowering (arrowing) phenomena will be discussed in the next section, while the varietal effect is considered in Section V, and illustrated in Figs. XVI-XXIX.

IV. THE EFFECT OF ENVIRONMENT ON THE GROWTH OF SUGAR CANE IN BARBADOS.

In Barbados sugar-cane is planted towards the end of the rainy season, i.e., November and December of any year; it grows throughout the following year and is reaped during the early months of the subsequent year—in all a growing period of approximately fifteen months.

Four climatic periods may be conveniently recognised in any growing season, i.e. (1) the planting period, November and December, (2) the dry-season period January-May, (3) the rainy season period June-December, and (4) the crop period January-April.

The section on the environment indicates the salient climatic features of these periods. Season and place differences—especially in rainfall—serve to emphasize the effect of environment on sugar-cane growth.

The effect on the various observed growth-manifestations are considered here.

Tillering (Figs. VII and VIII). The time and, to a lesser degree, the extent of cane production is dependent on tiller production; hence the importance of tillering. A study of the graphs illustrating tiller production and rainfall shows that the time and extent of tillering is largely governed by the amount and distribution of the rainfall.

There is, as might be expected, a strong urge on the part of the stools to tiller in the earlier stages of growth, i.e., during the dry-season months. Sooner or later during these months, soil moisture,—related to rainfall,—exercises a limiting effect on this urge.

Thus, as the moisture in the soil diminishes as the dry-season progresses, tiller production diminishes (Figs. VII and VIII, March, April, May). The average of the four years shows that tiller production increases through January and February and part of March, and declines during the end of March, April and May.

Tiller production in amount and time, during the dry-season is variable from year to year. This variability is important and appears to be dependent on the rainfall during the dry-season months and perhaps to a lesser extent in the earlier stages, to the extent of moisture carry-over from the previous rainy season.

At Graeme Hall, in 1929, rain in February caused tiller production to go on favourably during March. From that time until the end of June, very low rainfalls were experienced. This caused tiller production to drop almost to zero during May and June.

At Vaucluse, the drop during April was arrested by a rainfall in May which sustained and even increased tiller production.

In 1930 the dry season at both places was very marked until June. Tiller production was low (see also Figs. XI and XII).

In 1931 at Vaucluse, rainfalls in February and April caused an average tiller production until May. At Graeme Hall the dry season was very marked and tiller production was low until May.

In 1932, both places experienced comparatively good rains during the dry-season months. This caused a high tiller production during the dry-season.

The time of arrival of the rainy season varies. Thus, May and June may have comparatively low rainfalls. This is especially so at the lower-rainfall station, Graeme Hall. When the rainfall does increase appreciably, tillering is affected to a greater or less extent. This depends on the extents of the rains and the previous tillering.

In 1929, at Graeme Hall, low rains were experienced in May and June. The July rainfall was good. The severe check exercised by the low rainfall in May and June stunted the tillers already present. This condition of the tillers coupled with high July rainfall caused an excessively high and late tillering throughout July and August. A maximum tiller production occurred late in the year (Fig. XII). Very few tillers were produced from September to the end of November, in spite of good rainfall. Tiller production rose slightly in December. This high, late tillering is chiefly attributed to the prolonged low-rainfall conditions in May and June and happened despite a good early dry-season tillering.

In 1929, at Vaucluse, there was no severe check during May so that tillering was sustained during this month and moreover, the tillers continued to make reasonable growth. In June, tillering and the growth of tillers received a slight check. The July rainfall was good and a consequent considerable tillering took place. The August, September and November rains were high; but, despite this, tiller production fell off gradually during those months.

In 1930, at Graeme Hall, rainfall was low until August. Tiller production was low up till that month and the stools were badly stunted. The August rainfall was good, but September was a very low-rainfall month. Thus, tiller production which had increased during August, fell quickly during September, during which month tiller growth was again checked. The subsequent months showed alternately high and low rainfalls, with resultant tiller flushes, alternating with severe checks to stool growth. The September to December tiller production at Graeme Hall in this year was much higher than that of the other years. This may be attributed to tiller flushes following persistent checks to the growth of the stools during recurrent low-rainfall spells.

At Vaucluse, in the same year, considerable rains fell from June to August. These came after the stools had been severely checked during May and after a low dry-season tillering (Figs. VIII-XII.). Conditions favoured a high tiller production which was sustained until August. The low rainfall in the middle of August reduced tiller production to a low figure and retarded growth. With better rains in September and October, tiller production again increased and was high until December.

In 1931, at Graeme Hall, the dry season rainfall was low and tiller production was also low. The rainy season came in early, i.e. at the end of May. Thus, an early high tiller-production took place. Rainfall was plentiful until December. There was a gradual decline in tiller production, in spite of plentiful rains from July onwards.

At Vaucluse in the same year, owing to better rains in the dry season, a higher number of tillers were present, relative to other years, than at Graeme Hall. When the early high rains came in at the end of May, a high tiller production followed. Despite good rains in July, there was a decline in tiller production. A second high production occurred in August and again, although smaller, during October, November and December.

In 1932, the comparatively high rains during the dry-season months encouraged high tillering with no severe check to growth. This had a striking effect on the rainy-season tillering. At both places, it is seen to be comparatively low during the early rainy-season, and is negligible from September onwards. (This feature has been found, in a more exaggerated form, in the recent 1933 measurements at Codrington. Here, the majority of the tillering was completed as early as April, and tillering after that month was low).

Tiller Deaths. (Figs. IX and X.) Death of tillers, from causes other than diseases or pests, is infrequent or almost absent during the dry-season months.

During the rainy-season the intensity of deaths rises more or less suddenly to a peak, with a sudden or gradual falling off. It is evident that each peak occurs, in each case illustrated, approximately two months after the corresponding peak for tiller production. Thus, for example, in 1932 at Vaucluse, tillering was high in April and, despite good rainfall in June and July, high tiller deaths occurred in these months.

Cane Production (Fig. XIII). The extent of cane production is dependent on the number of tillers which survive the critical period of root establishment.

Data was obtained for this feature in 1932 only. It is seen that the time of cane formation is dependent on the time of tiller production and the rainfall subsequent to the latter. The differences in rainfall in favour of Vaucluse, when compared with Graeme Hall, encourages a quicker cane production from the tillers at the former station.

In 1932, the majority of the canes was produced by August at Vaucluse and by September at Graeme Hall. Very small cane productions only occurred after these months.

Cane Length Increments (Figs. XIV and XV.) A comparison of the graphs illustrating this feature, with the graphs illustrating the rainfall (Figs. III and IV) will show that rainfall and cane growth are closely related.

Increments are negligible during the dry season. Moisture is the limiting factor to growth, and it would appear, available growth energy is devoted to the production of tillers.

In 1929 at Vaucluse, there was a sudden response in cane growth to rains in May, which was checked by a low June rainfall. Rains were then plentiful and growth increments high until October. At this time, as a result of the low rainfall, there was a sudden drop in growth increments. There was a feeble growth response to high rains in November and thereafter, in spite of high rains, growth decreased to a negligible amount.

At Graeme Hall in the same year, rains were low until June and growth was, as a result, retarded. The good rainfall in June was followed by a low July rainfall, but it is seen that there is, throughout, a progressive increase

in growth to the high rains in September. Rains were plentiful until December, but the increments decreased rapidly during late November and December.

In 1930, at both places, rainfalls alternated from average to very low. The growth increments never reached a high figure at any time, except at Vaucluse in October and December. Growth at Graeme Hall was very poor throughcut.

In 1931, high rains occurred early at both places and persisted almost throughout the rainy season. Exceptionally high increases were obtained during the early rainy-season months. The increases gradually lessened, and at Graeme Hall were actually less during September, October and November than in those months in 1929 and 1932.

In 1932, increments at Vaucluse were appreciable in May and June, after a favourable dry-season rainfall. The rainfall was favourable up to October and high increments were recorded. Further records could not be obtained, as a result of the canes arrowing heavily and lodging badly.

At Graeme Hall, the rains in June were sufficient to give average increases. A low July rainfall slightly lessened the expected increase in increments. The August rainfall was good and favoured high increments, but these again were lessened by a low September rainfall. The increments increased to a high figure in October, were again lessened by low rains at the end of the month, but rose to a high figure during the good rainfalls in November. December was a high rainfall month, but growth increments decreased to a very low figure.

Arrowing. The importance of arrowing, in considering sugar-cane growth lies in its effect in stopping cane elongation.

Greater importance has recently been attached to arrowing in Barbados, owing to the importation and trial and use in breeding of Chunnee and Glagah nobilised varieties and several varieties of the Coimbatore series. During an average year about 80% of the canes of these imported varieties arrow, whereas about 15% only of the canes of Barbados varieties arrow.

Arrowing occurs in Barbados during October, November and early December. This arrowing period is remarkably constant from year to year. It has already been seen that considerable cane vegetative-growth may occur in these late months, more particularly in the low-rainfall district. In some cases, such late growth provides the greater part of the yield of the subsequent crop. Thus, pronounced arrowing is undesirable.

Arrowing data was obtained from the breeding station and observations were made during growth recording. There are considerable differences between varieties in arrowing intensity, but also, within varieties, arrowing intensities are influenced by external conditions. The tendency for any cane to arrow, is, among other factors, influenced by its age and the length of time during which it has made efficient growth prior to the arrowing period. It appears that the older the cane and the longer the time during which it has made efficient

growth, the nearer is its attainment to some internal state which renders it susceptible to arrowing. These predisposing factors are promoted by long favourable growing conditions prior to the arrowing period.

Arrowing data for varieties in the breeding station, when compared with growth measurements in the same varieties, indicate that, in any variety, the tendency towards early and considerable arrowing is associated with a tendency to a shorter vegetative growth-period in its canes. Thus, intensity of arrowing is of use as an indicator of the duration of the cane vegetative growth. The latter, as will be seen in the subsequent sections, is important when considering the possible value of varieties to ecological areas.

Discussion on the Growth of the Sugar-Cane in Barbados.

A consideration of the features of growth and development already presented in this section, reveals the importance of the season and place rainfalls on the extent and time of their occurrence. Temperature appears to exercise a limiting effect on cane increments during December, and the early months of the reaping season. From March until November the growth expressions are largely controlled by the rainfall. The effects of this factor are discussed here.

In regard to tillering, the greatest urge to tiller is in the early months of growth, that is, during the dry season (1932). In spite of low moisture conditions at this time, tillers are produced and do not readily die. Nevertheless, moisture conditions are often so low in March, April and May as to inhibit active tillering (1930, Graeme Hall, 1931, and May and June 1929).

When tillering is active in a dry-season of above average rainfall and is not followed by an appreciable check to growth prior to a good rainy-season, tillering during the latter is low (Vaucluse 1932). A high tillering early in the dry-season followed by a slight check to growth, favours a minor tiller flush during the rainy-season (Graeme Hall 1932). High tillering during the early part of the dry-season, followed by a prolonged low-rainfall period (Graeme Hall 1929) results in an excessively high tillering late in the rainy season. Low tillering during the dry season is always followed by high tillering in the rainy-season (Graeme Hall, 1930, 1931). The nature of tillering at Graeme Hall in 1930 illustrates the effect of low tillering during the dry-season when followed by a rainy-season of low rainfall with recurring very low-rainfall periods. The effect of the latter is to stop tillering and to stunt the stools such that high tillering results during the intermittent rainy periods. Thus the stools accumulate an excessively high tiller number throughout the rainy season and effective cane growth under the conditions is impossible.

In summary, under optimum moisture conditions, the natural tendency of the stools is to produce tillers early such that a chart of tiller-production-in-time would resemble, during the dry-season months, a normal growth curve and subsequent tillering during the rainy-season months would be negligible. This natural tendency is, however, usually interruptetd during one or more periods of moisture shortage. On the return of favourable moisture conditions there is a tendency to resume and, in many instances, to exceed the normal tillering.

A resumption of the normal production follows a short check to growth due to low soil-moisture content. A subsequent production high above the normal follows a longer check; the extent of this production being in proportion to the duration of the check and in inverse proportion to the extent to which tillers had been produced prior to the check.

From the practical standpoint, in the case of the existing commercial varieties, it would appear to be advantageous to have maximum tillering during the months of May, June and July (1931). Stools which produce the majority of their tillers earlier than May, undergo the likelihood of subsequent severe checks to growth. This in turn disposes towards superfluous later tillering which overburdens the stools (Graeme Hall 1929). Without such checks to growth, (Vaucluse 1932), cane formation is early and such canes experience a very long growing-season which results in higher arrowing and more extensive lodging. When the bulk of the tillering occurs late in the rainy-season (Vaucluse 1930, Graeme Hall 1929) cane formation is delayed and this results in shorter canes at crop. Repeated tiller flushes during the rainy season (Graeme Hall 1930) promote the development of stools with an abnormally high number of tillers, most of which cannot, under the conditions prevailing, produce canes. At the same time, their growth has a detrimental effect on the growth of the existing canes.

Maximum tillering during May, June and July is undoubtedly encouraged by a low-rainfall dry season and possibly as planters have stated, by later planting, coupled with good rains during those months. Canes emerging from tillers produced at that period, possess better width at the base than the earlier emerging canes, are likely to have a long growing season, do not arrow nor lodge so readily as the earlier formed canes and are comparatively sounder during crop. Moreover, under such conditions, the high tillering during May, June and July tends to encourage a large stool production at that time. This latter discourages later superfluous tillering.

It follows from the above considerations that greatest importance would be attached to the early rainy-season rainfall in so far as the subsequent crop tonnages are concerned. The results from an unpublished statistical investigation into the effect of rainfall distribution on the tonnages of the variety White Transparent, wherein tonnages were correlated with rainfalls of arbitrary periods, show that the most effective rains are those during the months of May, June and July.

The grand period of cane growth may be hastened or retarded according to the rainfall amount and distribution.

It is seen that, generally, cane growth is earlier and completed sooner at Vaucluse than at Graeme Hall. This is in accordance with the differences in rainfall amounts and distributions at both stations.

At Vaucluse in 1929, 1931 and 1932, growth increments increased from May to a maximum in and around August, decreased gradually to November, and finally decreased suddenly in December. In 1930, rainfall shortage retarded

cane growth, so that when rains were adequate in the months of October and even December, growth was higher in those months than in the corresponding months in the stated better rainfall years.

At Graeme Hall, the year 1931 illustrates cane growth under adequate rainy season moisture conditions. Following the early rains, there is a sudden increase in cane growth. Cane growth reaches a maximum in July and August, then lessens gradually until December when there is a sudden drop in increments. Cane growth during 1929 and 1932 illustrates the effect of retarded early rainy-season growth, and, it is to be noted, maxima in these years are recorded as late as September, October and November. The increments in these months exceed those for the corresponding months in the excellent rainy season in 1931. The sudden diminution in growth in December in these two years is again evident. The detrimental effect on cane growth of a rainy season with recurring very low rainfall spells, is illustrated by cane growth at Graeme Hall during 1930. It is of interest to note that during this year there is a definite tendency for a good late growth to be made, whenever rainfall is better. For example, during October and November 1930, the 1931 growth for these months is at least equalled.

It is thus seen that cane growth periodicity can be hastened or delayed. It appears that, given a sufficiently long favourable growing-period, canes will attain, or approximately so, their inherent lengths prior to becoming senescent. It is seen, however, that cane growth is always retarded in December and January, irrespective of the previous cane growth history.

In this respect, Quintius, dealing with cane growth in Java, ascribes the diminution in growth towards the end of the growing season, to a periodicity effect rather than to the effects of external circumstances. "The effect of peri-"odicity is, therefore, greater than that of rains; for the decrease of growth "continues in spite of the fact that there is often an excess of moisture left."

This well defined growth periodicity might be expected in the fast growing, quick maturing, uniform Java canes under the sustained favourable growing conditions of Java. The slackening of growth in such varieties when grown under favourable conditions in Barbados, would suggest that growth is approaching completion (a periodicity effect) and that any further appreciable growth responses even under prolonged favourable conditions woud be unlikely. However, in Barbados, when conditions are such as to promote late-season cane growth in Barbados varieties and in P.O.J.2878, and, in the case of late-formed canes ("October" or "water shoots") in varieties like B.417, B.2935 and P.O.J.2878, there would appear to be potentialities for further appreciable growth in December and January. Yet, any cane growth in these months is comparatively small.

In these instances, it is possible that the effect of the shorter day combined with the lower temperatures experienced with considerable regularity during the latter part of December and in January, may be, at least in part, responsible for this diminished growth. The average minima at this time drop to about 69.5°F-71.5°F. These minima are recorded during the night. The Java researches have shown that the sugar-cane plant makes its greatest growth

during the night (Quintius p.49). Lopez Dominguez in Peru, and more recently Hill and Evans in Mauritius, have shown the limiting effects of such temperatures to growth.

The extent of this drop in growth is influenced by the duration of the grand period of growth in the canes of the variety combined with the previous growth histories of the individual canes as determined by the time of their production and the extent and distribution of the subsequent rainfall.

The effect of these factors on growth increments during the harvesting season and on the extent of rotting in canes is being investigated in the maturity experiments and forms a distinct though complementary series of investigations to the growth measurements.

In concluding this section, it is seen that tiller production, cane production and cane length-increments are all influenced in time and extent by rainfall amount and distribution and that all lessen to a comparatively very small extent in December and during the reaping season. The length of favourable growing-season is, therefore, dependent on the time of commencement of the rainy-season and the subsequent degree of persistence of the rains.

V.—THE GROWTH RESPONSES BY VARIETIES.

The varieties measured, with the years of measurement of each, are detailed in Section II of this paper. For each variety, in each of the years of its measurement, growth of its above-ground parts was ascertained by noting the fortnightly production of tillers and canes (1932 only), the death of tillers and cane growth-increments. In the graphs, a selection of the measured varieties has been made to illustrate the development of these features and to bring out the salient varietal differences in them. The measured features are in turn considered here.

Tiller Production (Figs. XVI.–XXIII). In general, the effects of the environment on tillering are similar for all varieties. These effects have already been considered in Section IV.

The essential distinction between varieties lies in the time of production of tillers.

Tiller production in three Barbados varieties, Ba.11569, B.726 and B.H.10(12), is illustrated in the entire series of figures. They provide an interesting contrast.

In Ba.11569, there is a tendency to produce tillers early and to lessen tiller production comparatively soon. In B.726, tillering is also early, but is prolonged slightly later than in Ba.11569. In B.H.10(12), tillering is slower in the early months, but increases gradually and is prolonged over a greater period than the other two varieties. In B.891, there is an early and prolonged tillering (1931). In P.O.J.2878, tillering is very early and rapidly diminishes (1932).

Tiller Deaths. (Figs. XXIV-XXV. Figs. for 1929, 1930 and 1931 excluded.) These are high in the Barbados varieties and low in the Java and Coimbatore varieties. The high tillering capacity of the Barbados varieties is offset by the high death-rate of the tillers. It is noticeable that the graphs illustrating this feature show a close similarity to those for varietal tiller-production with a lag of about one to two months.

Cane Production (Figs. XXVI–XXVII). The graphs for cane production (1932) show that this feature is essentially related to tiller production in amount in time.

Cane Growth Increments (Figs. XXVIII-XXIX. Figs. for 1929, 1930 and 1932 excluded). The graphs chosen to illustrate this feature show that in a year of good rainy-season rainfall, there is little difference between the growth increments of four Barbados varieties during the earlier good growing months. From September onwards, however, it is seen that the variety B.891 drops off in cane growth quicker than the other varieties. This reveals the existence of differences between varieties in the duration of the vegetative period in cane growth. This is a highly important point when considering the adaptability of varieties to different lengths of growing-season. As noted previously, intensity of arrowing is a further indication of the comparative duration of the cane vegetative period in varieties.

The two chief distinctions in growth between varieties are thus seen to lie in, (1), the time of tiller and consequent cane production, and (2), the duration of vegetative growth in the canes. On these bases, the measured varieties are classified into growth-types*

Type I. Co. 213 (*P.O.J.* 36) In this type tillering is early and high and soon diminishes. The stools change abruptly from the tiller to the cane stage, which change usually coincides with the start of the rainy-season. Tiller deaths are comparatively few. These early canes tend to be uniform in age and appearance. The duration of the cane vegetative growth-period is very short, as revealed by the intense and early arrowing. As a response to the completion of cane vegetative-growth, a new flush of tillers is produced. These grow quickly and form thicker canes which make considerable growth before the induced slow growth of December onwards.

Type II. P.O.J. 2878 (*P.O.J.* 2725). This type differs only from the above in a slightly later emergence of the canes from the tillers. The cane vegetative growth-period is short (shorter in P.O.J.2725 than in P.O.J.2878).

*Type III. B.*417 (*B.*2935). All the measured Barbados varieties differ from the above types in that tillering and cane production are prolonged over a greater length of time, and there is not, as a result, such a well defined transition in the stool from the tiller to the cane stage.

* It is probable that, on the accumulation of further data, this provisional classification will be somewhat altered to render it more accurate. Nevertheless, in its present form, it provides in Barbados—as will be shown later—useful guidance in breeding, and more especially, in selecting sugar-cane seedlings for further trials.

In this type, tiller formation and cane emergence commence very early, the latter earlier than in types I and II. Tillering and cane formation are sporadic and last over a longer period than in types I and II. There is then a period of very low tiller production and cane formation, until the growth of the earlier canes slackens, when there is a minor tiller-flush from which a few canes emerge. These latter may attain a considerable size and weight before the reaping season commences.

The canes have a long vegetative growth-period, and although produced early in the growing season, make comparatively good growth up to December. (In this respect B.2935 exceeds B.417).

*Type IV. Ba.*11569 (*B.*465). In this type, tiller production is condensed into a shorter period than in the above type, but begins slightly later and is more intensive while it lasts. The major portion of the canes in the stool is formed comparatively early, and these canes are of a comparatively uniform age. These have a long vegetative growth-period. Late tiller flushes—as happen in the previous type—are unusual*

*Type V. B.*726. This type resembles type IV, except that tillering and cane production continue for a longer period.

The canes have a long vegetative growth-period. Late tillering and cane production are practically absent.

*Type VI. B.H.*10(12), (*B.*891 *and B.*374). In this type, tillering and cane production are prolonged over the greater part of the growing season. In B.891, tillers are produced over an exceptionally long period. The vegetative growth-period in the canes of B.891 is comparatively short; in B.H.10(12), on the other hand, it is very long.

VI.—THE SUITABILITY OF VARIETIES IN BARBADOS TO DIFFERENT ENVIRONMENTS, WITH SUGGESTIONS FOR THE PRACTICAL APPLICATION OF THE FINDINGS.

It has been shown that, in Barbados, the amount and distribution of the rainfall is the chief factor affecting the growth of the sugar-cane. On a basis of this factor, environments may be recognised. For convenience, two environments may be considered, that is, (1) where the rainy-season begins earlier and precipitation is higher and better sustained—the higher rainfall district, and (2) where the rainy-season begins later, precipitaton is lower and dry spells are liable to occur—the lower-rainfall district. They provide, respectively, a longer and a shorter growing-season.

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* This statement is made, as a comparative one between growth-types. Actually, as was shown in Section IV, late tiller flushes and late cane production are dependent, apart from variety, on the previous stool development as influenced chiefly by rainfall amount and distribution. In the case of late tiller flushes and late cane production, the comparisons between growth-types, as noted in this section, still hold, irrespective of previous stool development.

The reactions of the varietal growth-types—as presented in the previous section—to the longer and shorter favourable growing-seasons are presented here. (Results from reaping the maturity experiments are also used here).

(1) *Reactions of varietal growth-types to the longer favourable growing-season —the higher-rainfall district.*

Type I. (*e.g. Co.* 213, *P.O.J.* 36). Tillering and cane production are early and high. Little further tillering takes place until the completion of vegetative growth in these canes. The latter takes place very early in the arrowing season. A strong flush of new tillers, which produce canes, follows the arrowing. These late canes are thicker and weigh heavier at reaping than the early canes. During the reaping season, two well marked cane types are present in the stool. The early canes ripen earlier than the late canes. Both cane types show comparatively little tendency to rot during the harvesting period.

In view of the facts that the early canes lose comparatively little weight during crop and that the late canes require a longer period to ripen satisfactorily, this type may be regarded as a late-reaping type. This is an example of growth-type which, although possessing canes of a very short vegetative growth-period, is, by virtue of such canes retaining their weight during crop, essentially at its best late in crop.

These advantages are, however, outweighed by the disadvantages. The canes, by virtue of a short vegetative growth, cannot use the good growth conditions from mid-September onwards and are, as a result, comparatively short. The inherent tendency to diminish tillering after the first flush eliminates the possibilities of larger early cane stools. The canes are very thin and tonnages are made up by high cane numbers. This increases the labour necessary in cutting and transporting. As milling canes they are markedly inferior to the noble canes.

The disadvantage of the short cane vegetative growth-period is more marked in the ratoon crops, where again, arrowing is early and intense after a short growing-season from plant cane cutting until the arrowing season. The canes are very short under these circumstances (recent data from ratoon growth measurements).

For the above reasons such a growth-type is unsuited to the longer favourable growing-season in Barbados.

Type II (*e.g. P.O.J.* 2878, *P.O.J.* 2725). Tillering and cane production are early. The number of canes produced is, on an average, approximately 20% higher than in Barbados varieties. There follows a marked lull in tiller production. Cane growth is rapid but the vegetative growth-period is short and arrowing early and high. As with the above type, the reaction to the cessation of vegetative growth in the early canes is the production of late tillers, from which canes emerge. These latter are thick and possess great growth vigour which is diminished by conditions from December onwards and, at crop, weigh, on the average, slightly heavier than the early canes. At harvesting, two cane types

are present. So far, this type resembles the above. It differs, however, in that some of its early-formed canes die back early in crop, especially those canes which have arrowed and failed to produce side-shoots subsequently. With the further progress of the crop, the loss in weight from this dying-back does not increase to the same extent as in canes of approximately comparable Barbados growth-types. It would appear that the late-formed canes make very slow but steady growth during the harvest, and that this, in some measure, tends to counteract the loss in tonnage resulting from the drying-out in the early-formed canes.

The rate of juice ripening is retarded by a slow ripening in the late canes, so that juice optima are late in crop. Here again is a further example of a type which, although its canes grow fast and arrow early, is yet most suited to late reaping.

It is possible that it might succeed under a long favourable growing-season, in areas where arrowing is less prevalent, and where conditions during crop do not predispose towards drying-out to the extent that they do in Barbados.

The remarks in regard to ratoons, as made for Type I, apply here.

Type III. (*B*.2935, *B*.417). Tillering and cane production begin early, but are sporadic and extended over a longer period than in the previous types. The sporadic tillering leads to an average, or under average, cane production for Barbados varieties. This first cane production is succeeded by a lull in tillering. Individual canes are large and have a long vegetative growth-period; but under such conditions, the earlier produced ones may arrow. Around the arrowing season, tillers are again produced and these may produce a few late canes. These are thick, but shorter and lighter than the early canes.

At harvesting two cane types are present. The early canes are long and lodge readily and tend to rot early in crop. The late canes remain erect, but, owing to their short growing-period prior to crop, ripen slowly and retard the attainment of juice optima.

It appears that this growth type is entirely unsuited to the longer favourable growing-season in Barbados. The number of canes is less than could be supported by the conditions, the late canes retard juice ripening so that juice optima are late and, if waited for, the early canes have rotted badly and, as a result, tonnages drop markedly during crop.

Type IV. (*Ba*.11569, *B*.465). Tillering and cane production commence slightly later than in the above type but last over a shorter period. (In this respect this type bears a close resemblance to Type II). The canes are formed comparatively early and tend to be uniform. The older canes may arrow under long favourable growing-season conditions, in spite of their long vegetative growth-period. The production of late tillers and canes is negligible. The canes attain juice optima comparatively uniformly and early.

This is a type which produces comparatively early and uniform canes. Owing to the earliness in cane production and the long growing-season which

these canes experience, all are comparatively senescent at the commencement of crop. As a result, there is a tendency for rotting to take place, which may be very pronounced between mid and late-crop. Tonnage returns, as a result, drop heavily with the progress of the crop.

Type V. (*e.g. B.*726). This type resembles the above, except that tiller production and cane formation are further prolonged. As a result the stool is comprised of canes with a greater range of ages than the above type. The majority of the growth is slightly later. Late tiller and cane production is almost absent. The cane vegetative growth-period is long and arrowing is rare, except in a very early growing-season. Owing to the more extended cane-producing period here than in the previous type, rotting is more delayed in the crop. Juice optima are attained comparatively early.

This type is well suited to early reaping under such conditions, but runs a risk of losing tonnage through rotting, if kept too late in the crop.

Type VI. The outstanding feature of this growth type is a prolonged tiller and cane production. The canes at reaping represent a gradation from old to young. Prolonged tillering under the longer favourable growing-season conditions can be sustained, and exaggerated tiller production as a result of prolonged checks due to moisture shortage, are very uncommon.

Two varieties represent sub-divisions of this type, based on the length of the vegetative growth-period in individual canes.

In B.891, there is a short cane vegetative growth-period. As a result, although canes are many, they are short, reach an early juice optima and tend to rot with the progress of the crop.

In B.H.10(12), canes are produced over a comparatively long period. They also have a long vegetative growth-period and only the earliest produced canes arrow under long favourable growing-season conditions. A high number of canes are produced, which on the average, are younger than previous growth-types, are more vigorous when they enter the harvesting season and do not tend to rot to any extent. It follows also that juice optima in this type are later in crop.

This type is well suited to late reaping in districts with the longer favourable growing-season.

II. *Reactions of varietal growth-types to the shorter favourable growing-season—the lower-rainfall district.*

In general, in this district, cane production is later than in the higher rainfall district. In this respect all varieties are affected similarly. In the description below, time of cane production bears a varietal significance and is not compared with this feature in the higher-rainfall district.

Type I (*e.g. Co.* 213, *P.O.J.* 36). Tillering and cane production are comparatively early. The canes are uniform and grow comparatively well. Their

growth in length is terminated by arrowing at the beginning of October. Any further stool weight increase comes from the canes produced from the tillers which are produced during the arrowing season.

In general, the disadvantages of this type here are similar to those in the higher-rainfall district. An added disadvantage lies in its canes arrowing intensively after a very short favourable growing-season. As a result, very short canes are produced.

It was shown earlier that cane growth in the lower-rainfall district tends to be delayed, so that high increments may be obtained during and after the arrowing season. It is evident that canes, in order to reach a good length, must take advantage of late growth. Varieties which arrow so intensively as in this type have so far proved to be unsuited to this district.

Type II (*e.g. P.O.J.* 2878. *P.O.J.* 2725). Growth follows a similar course here as in Type I. In a very short favourable growing-season, P.O.J. 2878 may not arrow. Owing to a later growth in the short favourable growing-season, the tendency for canes to rot is much less marked than under the long favourable growing-season conditions. Thus, with the probable compensation of a slightly increasing late-cane weight during the crop, the loss in tonnage as the crop progresses is comparatively small. Juice optima are late in crop, but earlier than in the higher-rainfall district.

The advantage of this growth-type here lies in a high production of cane early,—a great advantage when the shortness of the growing-season is considered —and the almost total lack of tiller production after the cane-stool is formed— an obvious advantage under conditions where a shortage of rainfall may be experienced during the rainy season.

Its disadvantage lies in the vegetative growth-period of the canes being so short as to promote arrowing, when, on an average, little more than half the favourable growing-season has passed.

It is this disadvantage which allows Barbados varieties of an approximately comparable growth-type, but with a longer cane vegetative growth-period, to excel varieties in this growth-type under such conditions.

Type III (*e.g. B.*2935 *and B.*417). As a growth-type it is suited to the short favourable growing-season, for the following reasons; (1) canes are produced comparatively early, have a long vegetative growth-period and therefore grow effectively over the entire favourable growing-season, (2) the amount of tillering and cane production is more in keeping with the expected moisture conditions; thus the evil of superfluous tillering is avoided, and (3) late produced canes are under the environmental conditions prevailing in this district during the crop, forced to their juice optima comparatively early and yet remain sound to the end of the crop.

Type IV (*e.g. Ba.*11569, *B.*465). This type is well suited to the short favourable growing-season. The canes are uniform and the majority is produced early. They have a long vegetative growth-period and grow throughout

the favourable growing-season. Being produced later here than in the higher-rainfall district, they do not arrow to any extent. Late tiller production is reduced to a minimum and this gives the existing canes every advantage of the conditions to make good growth. In the uniform canes juice optima are attained comparatively early and rotting is not so marked as in the earlier formed canes of this type in the higher-rainfall district.

Type V. (*e.g. B.* 726). The canes are produced over a longer period than in Type IV and make growth, on the average, later. In a short favourable growing-season the growth may be so late that there is not sufficient time left for a full expression prior to the diminished growth rate in December. Again, owing to a longer period of tillering and cane production, checks to growth are more liable to occur during this period. This leads to superfluous tillering on the return of better moisture conditions. The canes, however, owing to their later production and long vegetative-growth period remain comparatively sound during the crop and losses of tonnage through rotting are low.

This type is evidently better suited to an intermediate length of favourable growing-season.

Type VI. In B.891, in the lower-rainfall district, there is a tendency to over tiller, so that the stools, especially following dry sells, tend to become a mass of tillers, whose presence retards the growth of the canes in the stool. The individual cane vegetative growth-period is short and a comparatively early and marked slackening of growth is seen, even in the lower-rainfall district. This leads to short canes which attain juice optima early, but which are also susceptible to rotting during crop.

In B.H.10(12), the disadvantage of its growth-type in the shorter favourable growing-season lies in its tendency to prolonged tillering with the majority of its canes emerging later than in previous types. Thus, in this district, there is not sufficient time for an effective expression of its potential cane growth. At the same time, such prolonged tillering requires frequent precipitations in order that an even and satisfactory cane production should result. Owing to the relatively long time devoted to tillering in this type, dry spells are likely to occur during this time in this district. This interferes with and further delays cane production, and tends to encourage a later higher tiller-production from which only very few canes have time to emerge.

Discussion.

In making preliminary selections of sugar-cane seedlings, features other than the growth-type considered above are taken into account, e.g., cane number and thickness, ease of trashing, resistance to disease, per cent. sucrose in juice, etc. It is evident that any seedling must possess some preconceived minimum requirement in each of these, in order to be considered for selection and further trial. Using such criteria as a basis for preliminary general selections among seedlings, it is then practicable by a system of growth-measurements and consequent recognition of its growth-type to determine, for each seedling, the length of favourable growing-season and time of reaping at crop to which it is best

suited. Accordingly, it is further tried under such conditions only. Thus, the extent of the area in which it need be tried and so the number of its trials is lessened. This promotes economy and greater efficiency in further trials. At the same time, the scheme may admit of a greater number of seedlings being tried in any series of trials. Finally, the confusion which previously arose out of the conflicting results obtained when testing a series of seedlings in districts representing a wide range in lengths of favourable growing-season, is, by this method, largely avoided.

It is possible that a variety which is of a growth-type best suited to a certain length of favourable growing-season may be best suited commercially to another environment—a general purpose variety. So far, no such variety has been experienced in the growth measurements in Barbados. It appears more and more evident from the experiences of sugar-cane growing countries, that special variety growth-types are adapted to give best results in certain environments. The general purpose sugar-cane variety is nowadays uncommon.

The findings from these growth measurements are now being used as a basis for allocating sugar-cane varieties for trial to their probable most suited environments in the sugar-cane growing islands in the British West Indies. Allocations are made on a basis of the growth-type determined from growth-measurements.

VII.—SUMMARY.

1. The paper presents the results of growth measurements made on several varieties of sugar-cane during the years 1929, 1930, 1931 and 1932, at a higher—and a lower-rainfall station.

2. During 1929, 1930 and 1931 the progress of growth was determined by measuring, at fortnightly intervals, tiller production, tiller deaths and growth increments in canes. In 1932, cane production was considered as a further indicator of growth.

3. The soil characteristics and nutrition at both stations are presented, the information being derived from the findings of the Agricultural Chemist in his work on the Barbados soils and from manurial experiments. Soil temperatures were taken at 4″ and 12″ depths at both stations.

4. The climatic factors, air temperature, air humidity, rainfall, wind velocity, and sunshine were recorded at both stations or from stations approximating to them.

5. The conclusions from a consideration of the environmental data are:

   (1) that the difference between the soils of both stations is negligible in so for as intrinsic capacity to promote growth is concerned;

   (2) that nutrition during the seasons of measurement was unlikely to exercise any appreciable limiting effect to growth;

(3) that, of the climatic factors, it is rainfall—its amount and distribution —and, to a lesser extent perhaps temperature, which serve to promote differences in growth between seasons and places.

6. The effect of environment—chiefly rainfall—on the growth of sugar-cane in Barbados is presented in Section IV.

7. The particular growth-responses by varieties is considered in Section V. This leads to a classification of varieties into growth-types, chiefly on a basis of the time of tiller and cane production, and the duration of vegetative growth in the individual cane.

8. In Section VI, the significance of this is considered in its application to the selection of varieties of suitable growth-types for trial in longer or shorter favourable growing-seasons.

In conclusion the writer desires to record his appreciation of the work of Mr. H. E. Ward, Second Field Assistant, in making the measurements at the higher-rainfall station, Vaucluse, and in making the detailed graphs for that station.

He also desires to acknowledge his indebtedness to Mr. C. C. Skeete, Assistant Director of Agriculture, for his permission to reproduce the graphs of the climatic data obtained at Codrington Experiment Station, and to Mr. G. C. Stevenson, Assistant Botanist, for drawing the summarised graphs presented in this paper.

VIII.—RELEVANT LITERATURE CONSULTED.

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Stubbs, W. C. Sugar-cane, I., Chap. XIV.

IX. GRAPHS.

FIG. I.

FORTNIGHTLY MEAN MAXIMUM AND MINIMUM SOIL TEMPERATURES ~ VAUCLUSE

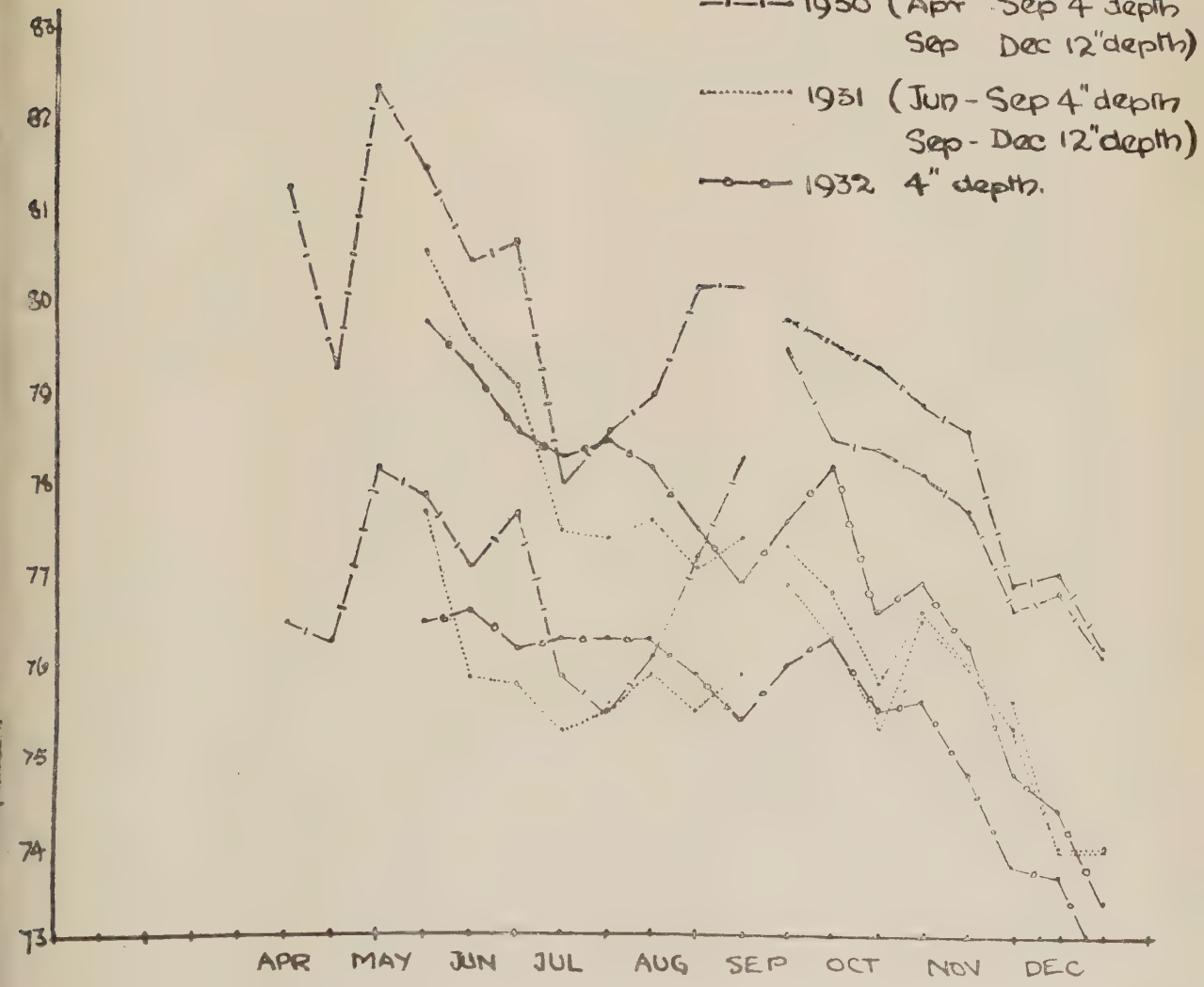


FIG. II.

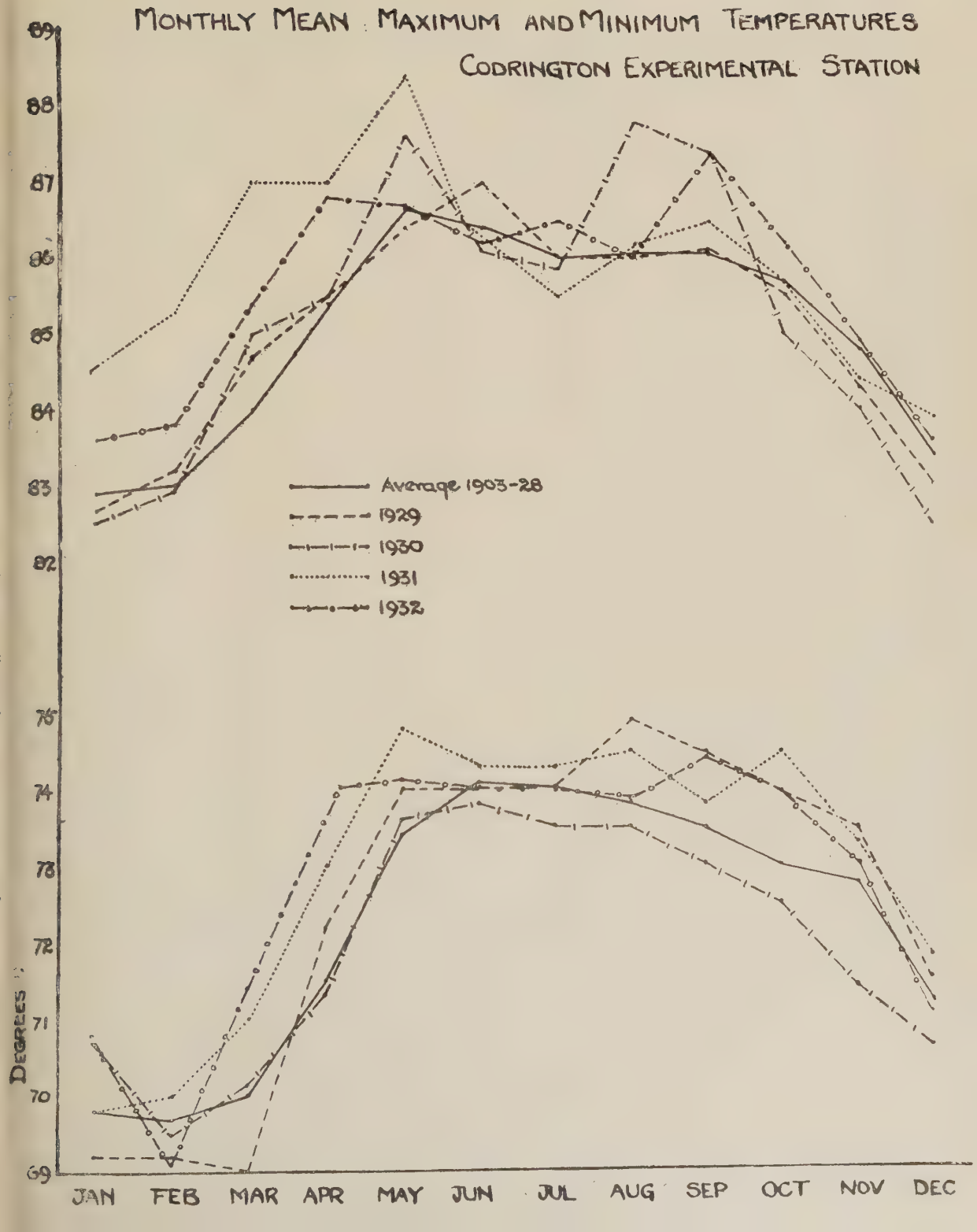

MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURES
CODRINGTON EXPERIMENTAL STATION
89
88
87
86
85
84
83
82
Average 1903-28
1929
1930
1931
1932
76
74
73
72
71
70
69
DEGREES F.
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. III.

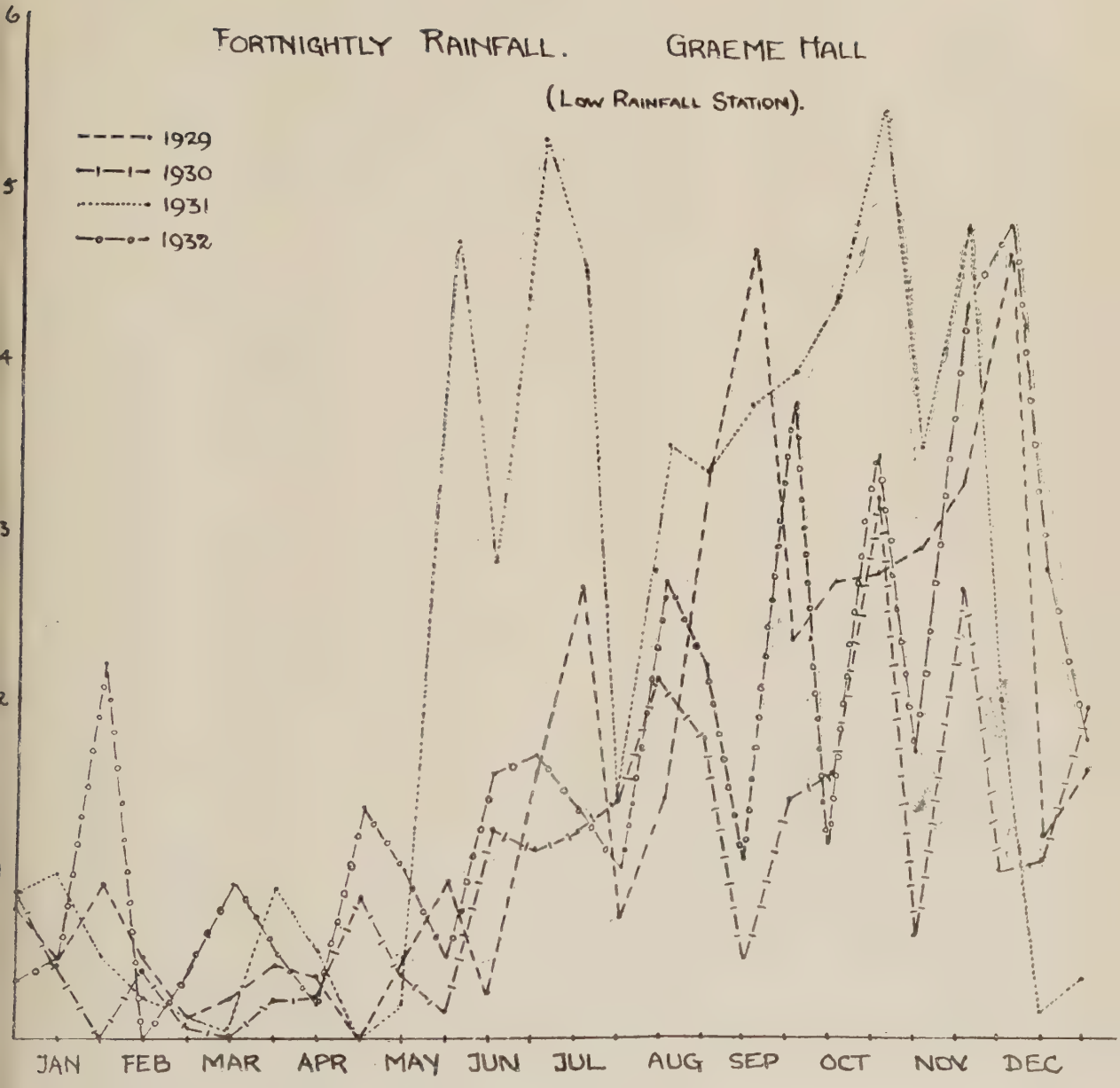

FORTNIGHTLY RAINFALL. GRAEME HALL
(LOW RAINFALL STATION).
1929
1930
1931
1932
6
5
4
3
2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. IV.

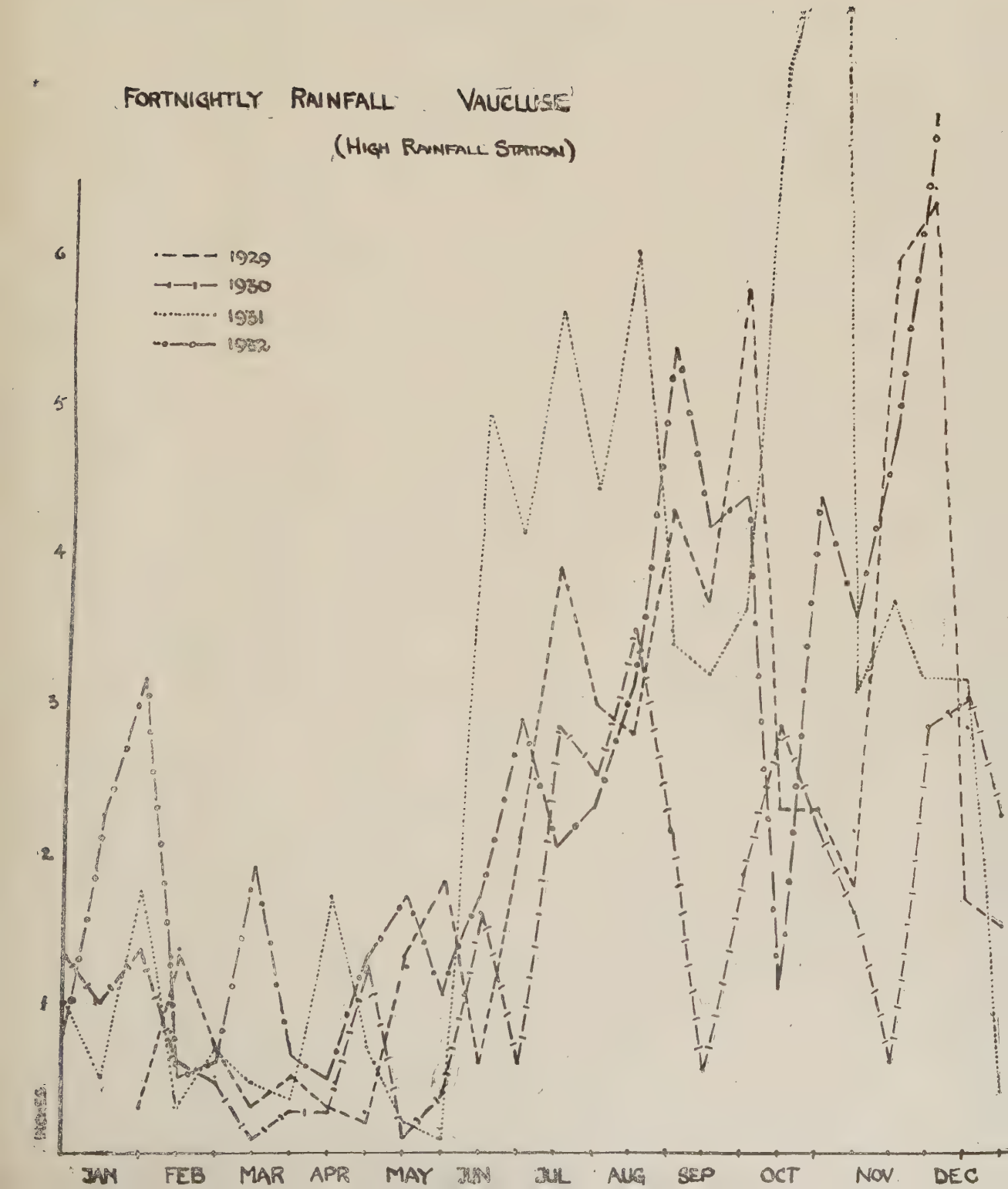

FORTNIGHTLY RAINFALL VAUCLUSE
(HIGH RAINFALL STATION)
1929
1930
1931
1932
6
5
4
3
2
1
INCHES
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. V.

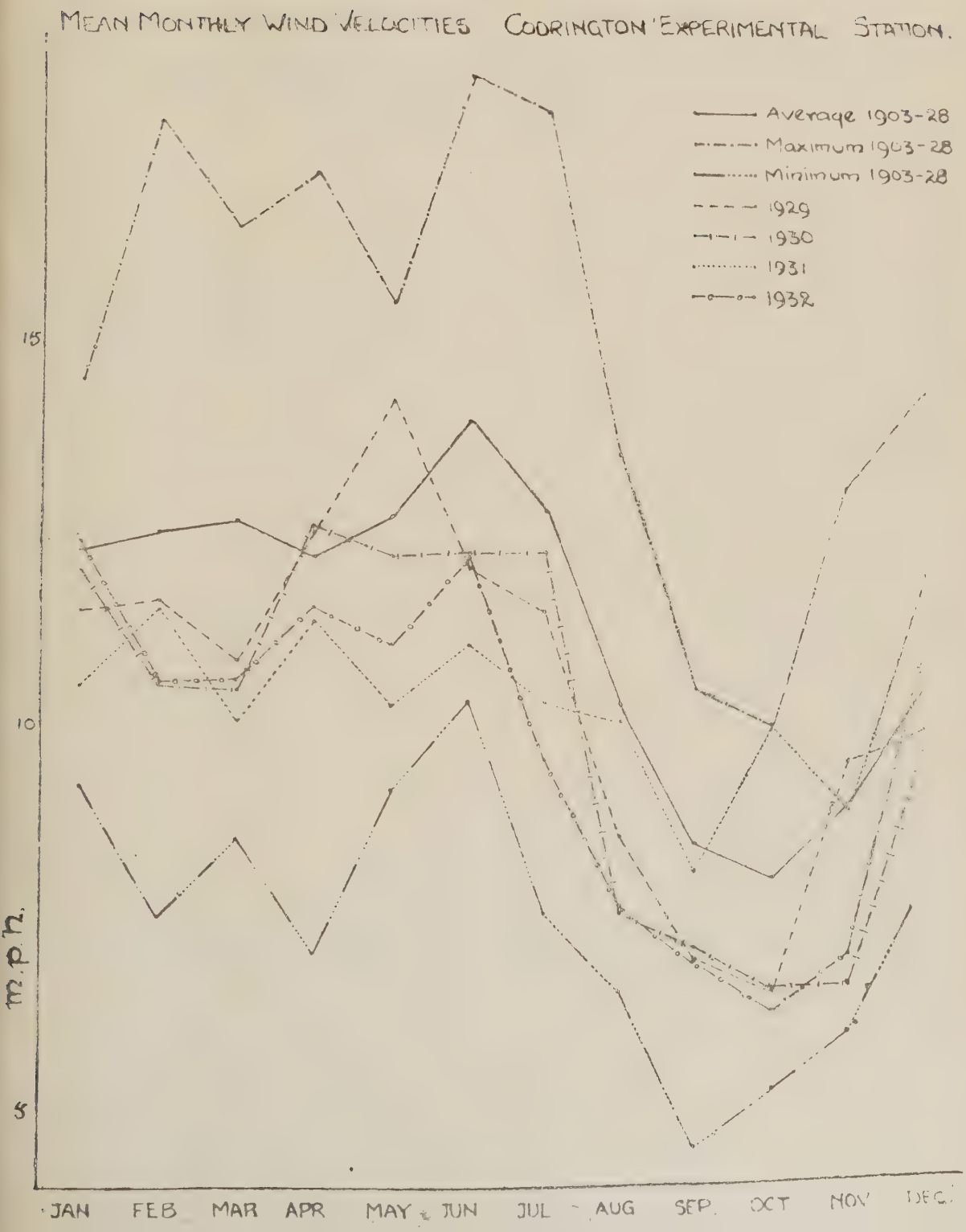

MEAN MONTHLY WIND VELOCITIES COORINGTON EXPERIMENTAL STATION.
Average 1903-28
Maximum 1903-28
Minimum 1903-28
1929
1930
1931
1932
15
10
5
m.p.h.
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP.
OCT
NOV
DEC.

FIG. VI.

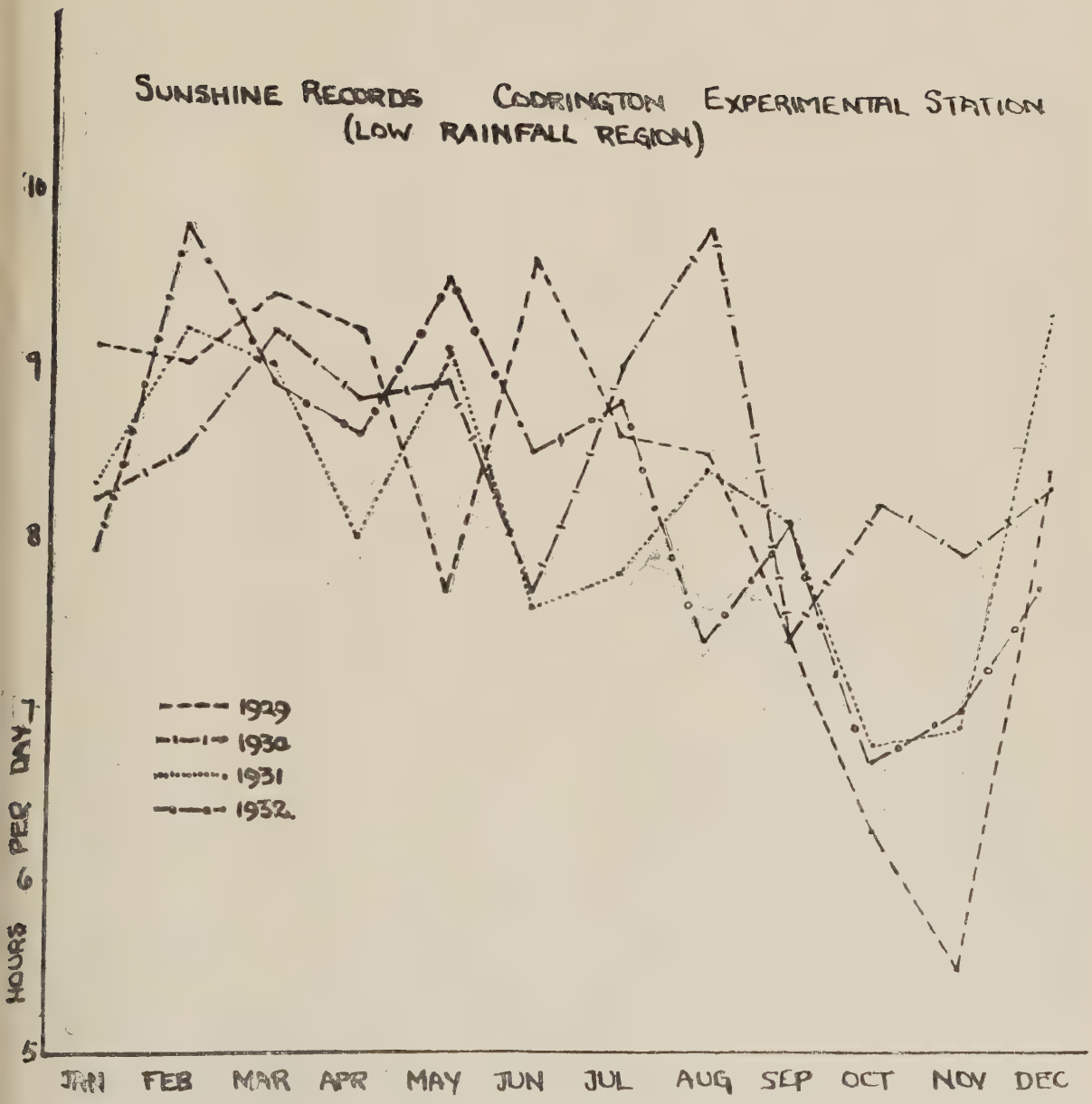

SUNSHINE RECORDS CODRINGTON EXPERIMENTAL STATION
(LOW RAINFALL REGION)
10
9
8
7
6
5
HOURS PER DAY
1929
1930
1931
1932
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

FIG. VII.

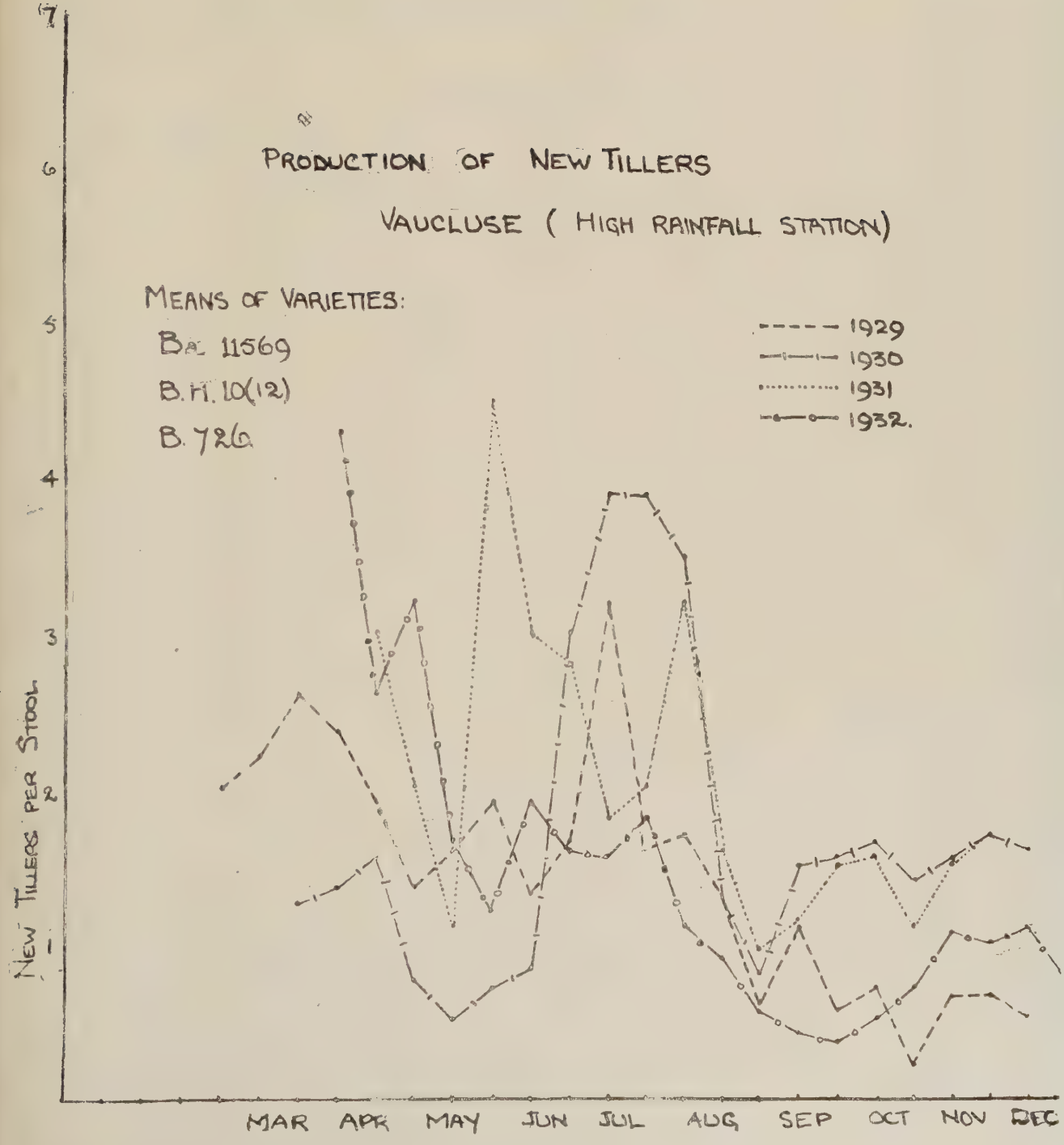

PRODUCTION OF NEW TILLERS
VAUCLUSE (HIGH RAINFALL STATION)
MEANS OF VARIETIES:
B.A. 11569
B.H. 10(12)
B. 726
1929
1930
1931
1932.
NEW TILLERS PER STOOL
7
6
5
4
3
2
1
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. VIII.

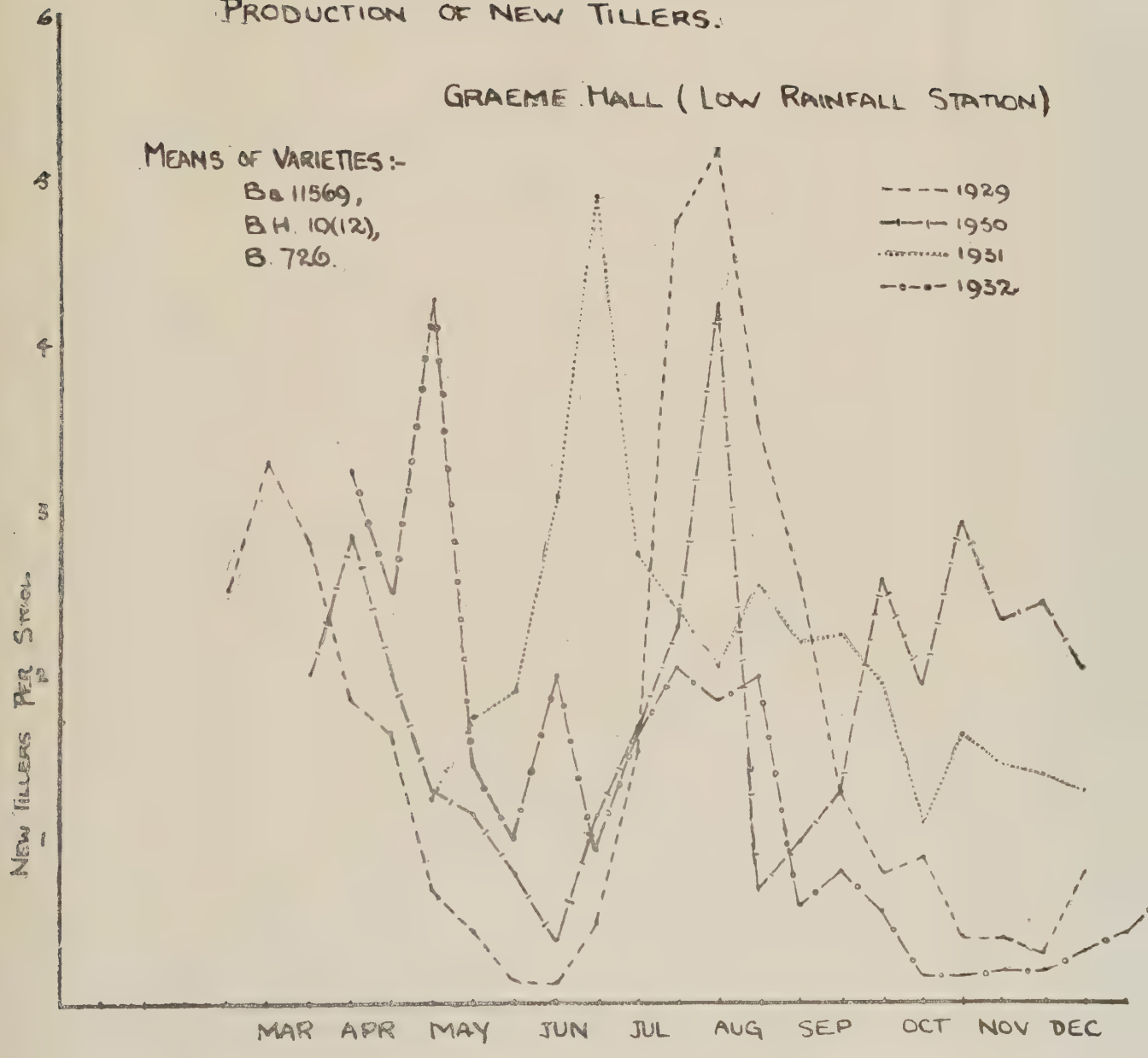

PRODUCTION OF NEW TILLERS.
GRAEME HALL (LOW RAINFALL STATION)
MEANS OF VARIETIES:-
B.a 11569,
B.H. 10(12),
B. 726.
1929
1930
1931
1932
NEW TILLERS PER STOOL
6
5
4
3
2
1
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. IX.

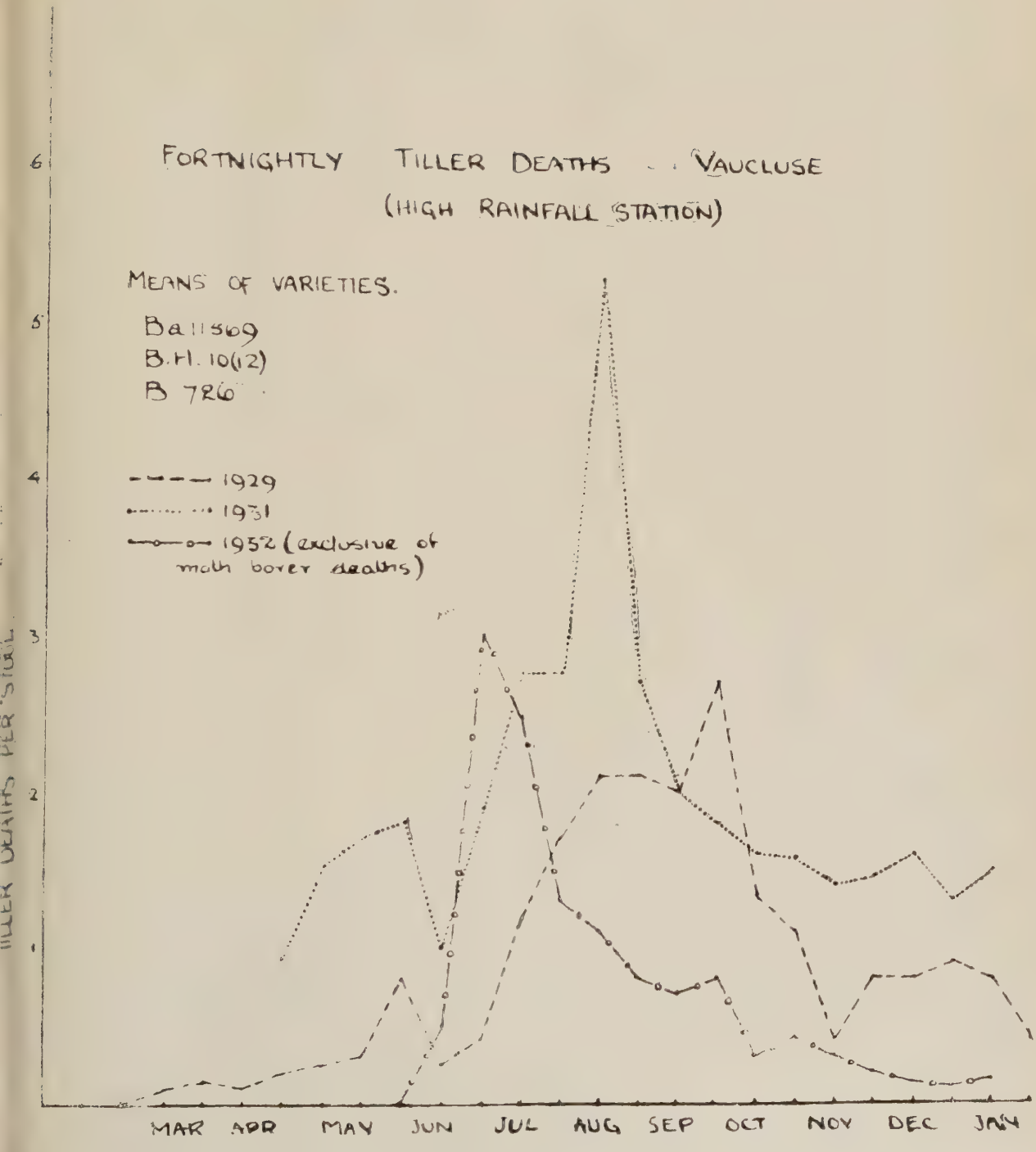

FORTNIGHTLY TILLER DEATHS . . VAUCLUSE
(HIGH RAINFALL STATION)
MEANS OF VARIETIES.
Ba 11569
B.H. 10(12)
B 726
1929
1931
1932 (exclusive of moth borer deaths)
TILLER DEATHS PER STOOL.
6
5
4
3
2
1
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. X.

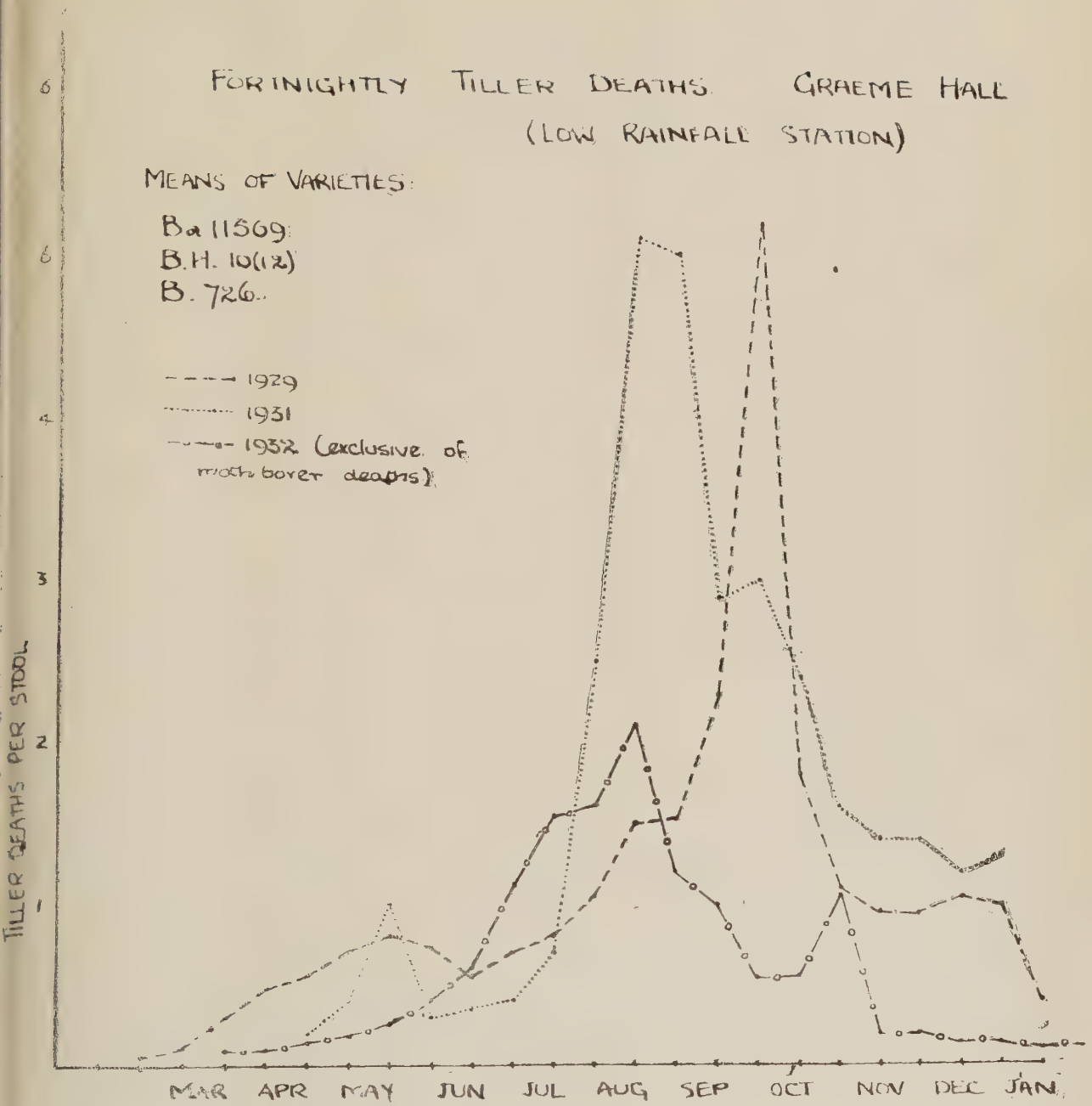

FORTNIGHTLY TILLER DEATHS. GRAEME HALL
(LOW RAINFALL STATION)
MEANS OF VARIETIES:
Ba 11569:
B.H. 10(12)
B. 726.
1929
1931
1932 (exclusive of moth borer deaths)
TILLER DEATHS PER STOOL
1
2
3
4
6
8
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XI.

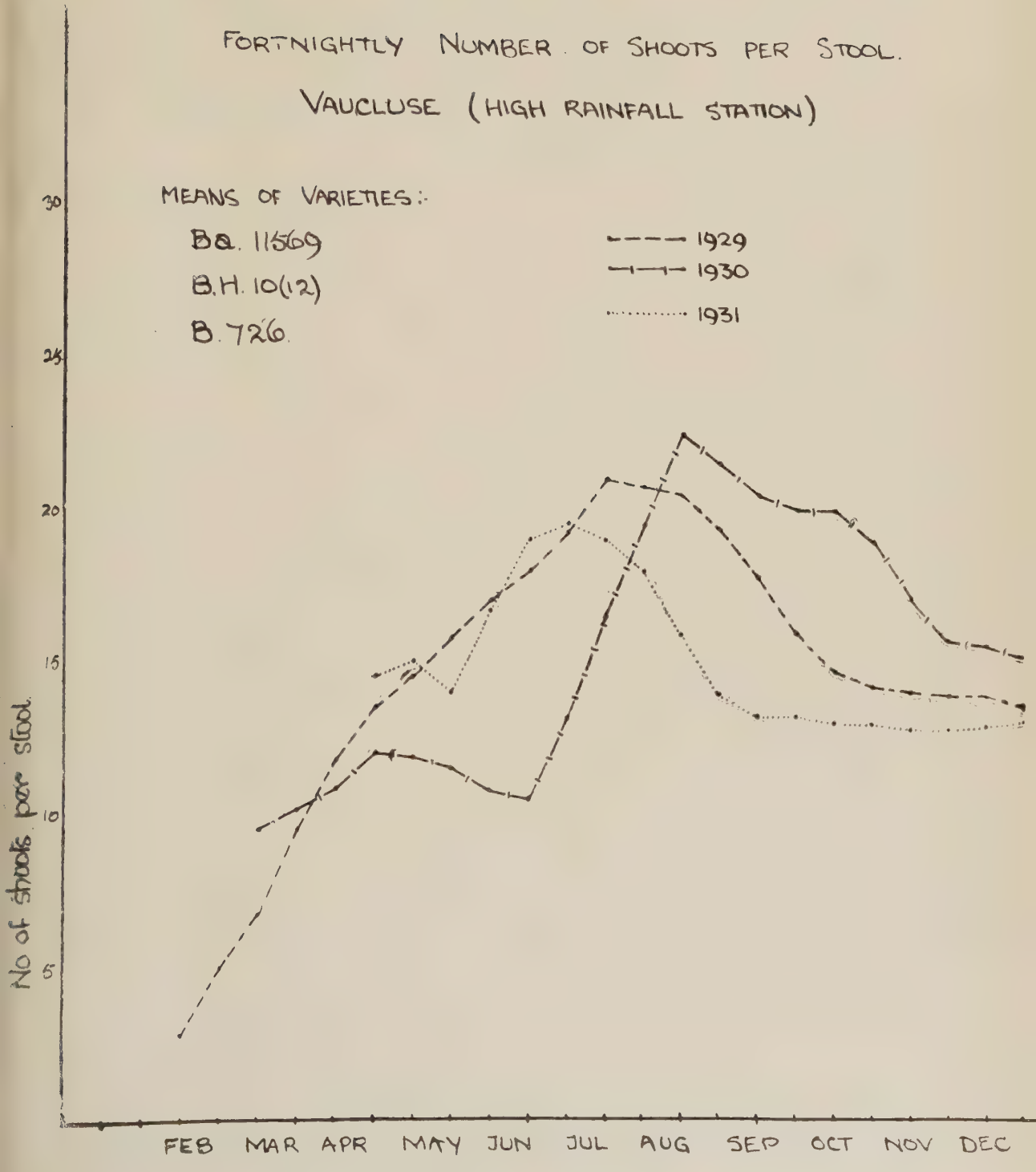

FORTNIGHTLY NUMBER OF SHOOTS PER STOOL.
VAUCLUSE (HIGH RAINFALL STATION)
MEANS OF VARIETIES:-
Bo. 11569
B.H. 10(12)
B. 726.
1929
1930
1931
No of shoots per stool.
30
25
20
15
10
5
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. XII.

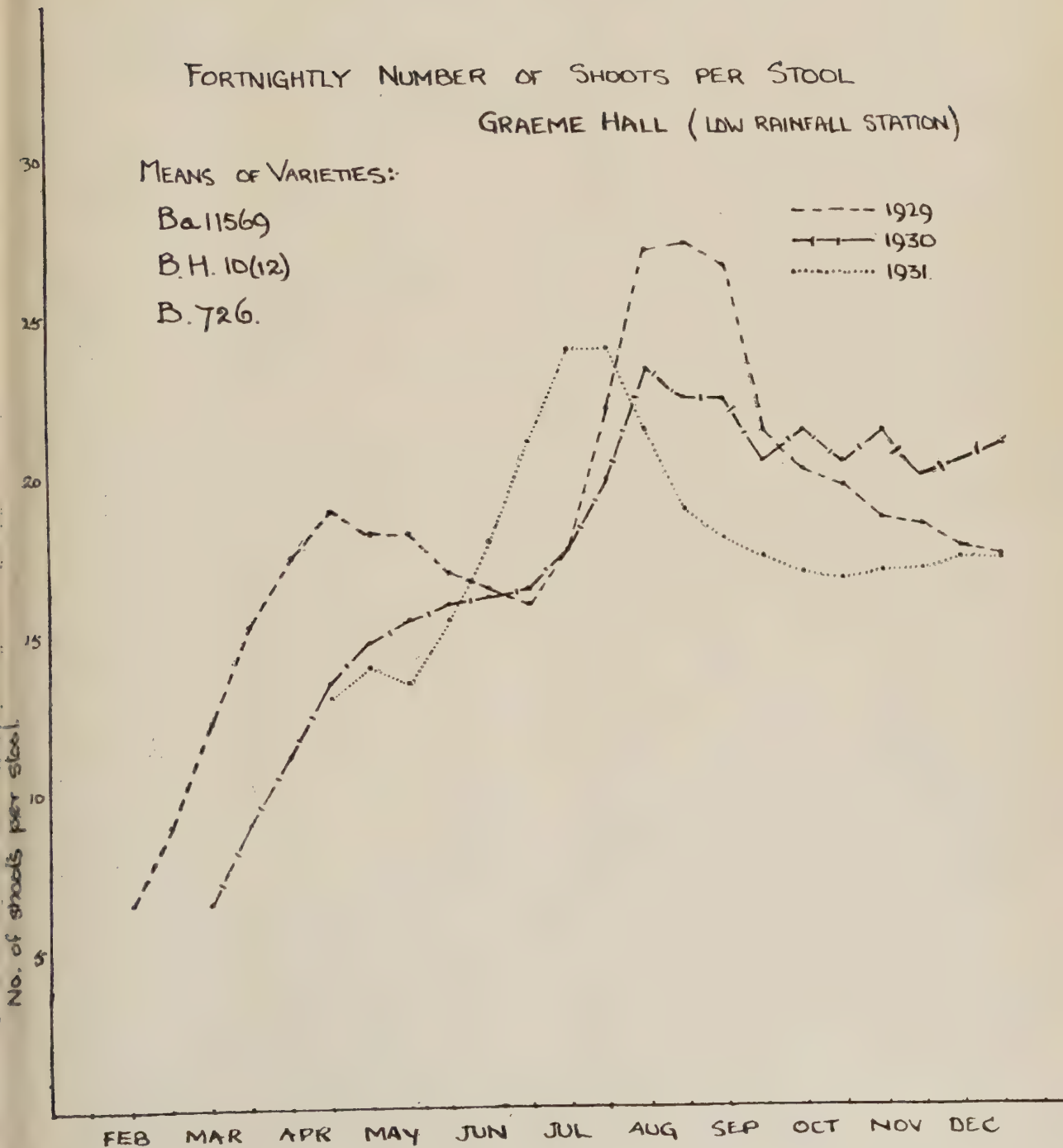

FORTNIGHTLY NUMBER OF SHOOTS PER STOOL
GRAEME HALL (LOW RAINFALL STATION)
MEANS OF VARIETIES:
Ba 11569
B.H. 10(12)
B.726.
1929
1930
1931
30
25
20
15
10
5
No. of shoots per stool
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. XIII.

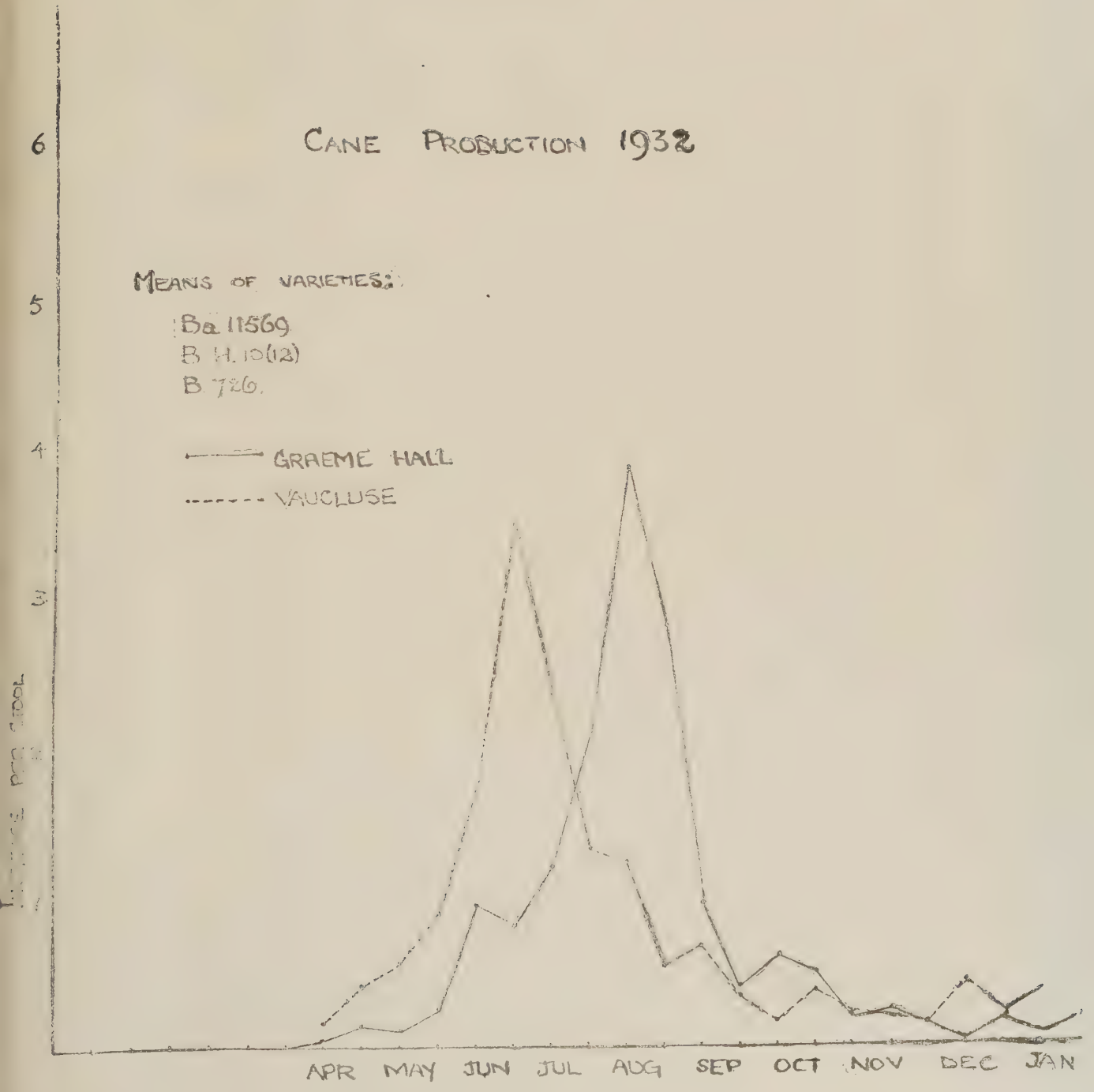

CANE PRODUCTION 1932
MEANS OF VARIETIES:
Ba 11569
B.H. 10(12)
B. 726.
GRAEME HALL
VAUCLUSE
6
5
4
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XIV.

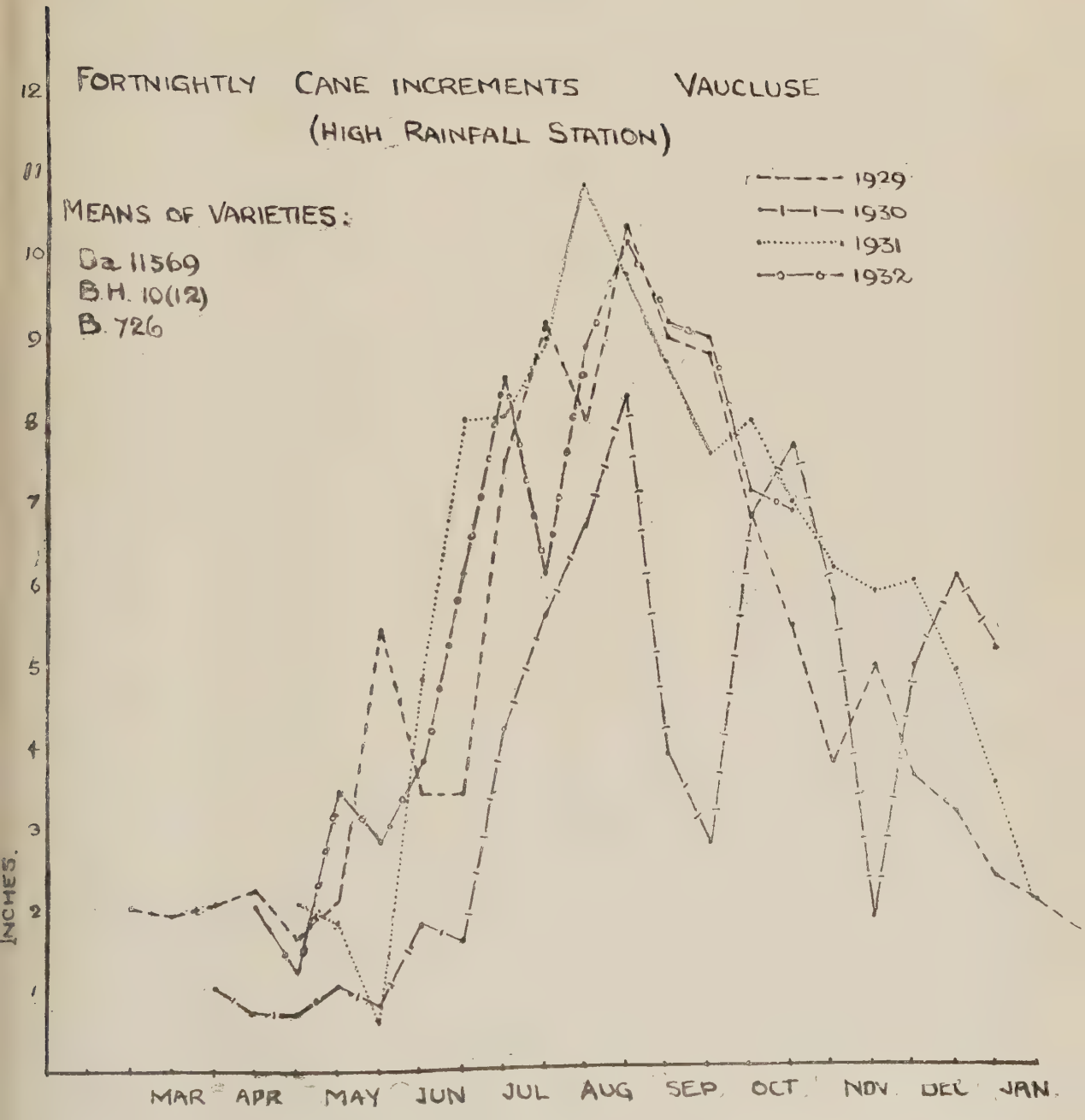

FORTNIGHTLY CANE INCREMENTS VAUCLUSE
(HIGH RAINFALL STATION)
MEANS OF VARIETIES:
Ba 11569
B.H. 10(12)
B. 726
1929
1930
1931
1932
INCHES.
12
11
10
9
8
7
6
5
4
3
2
1
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XV.

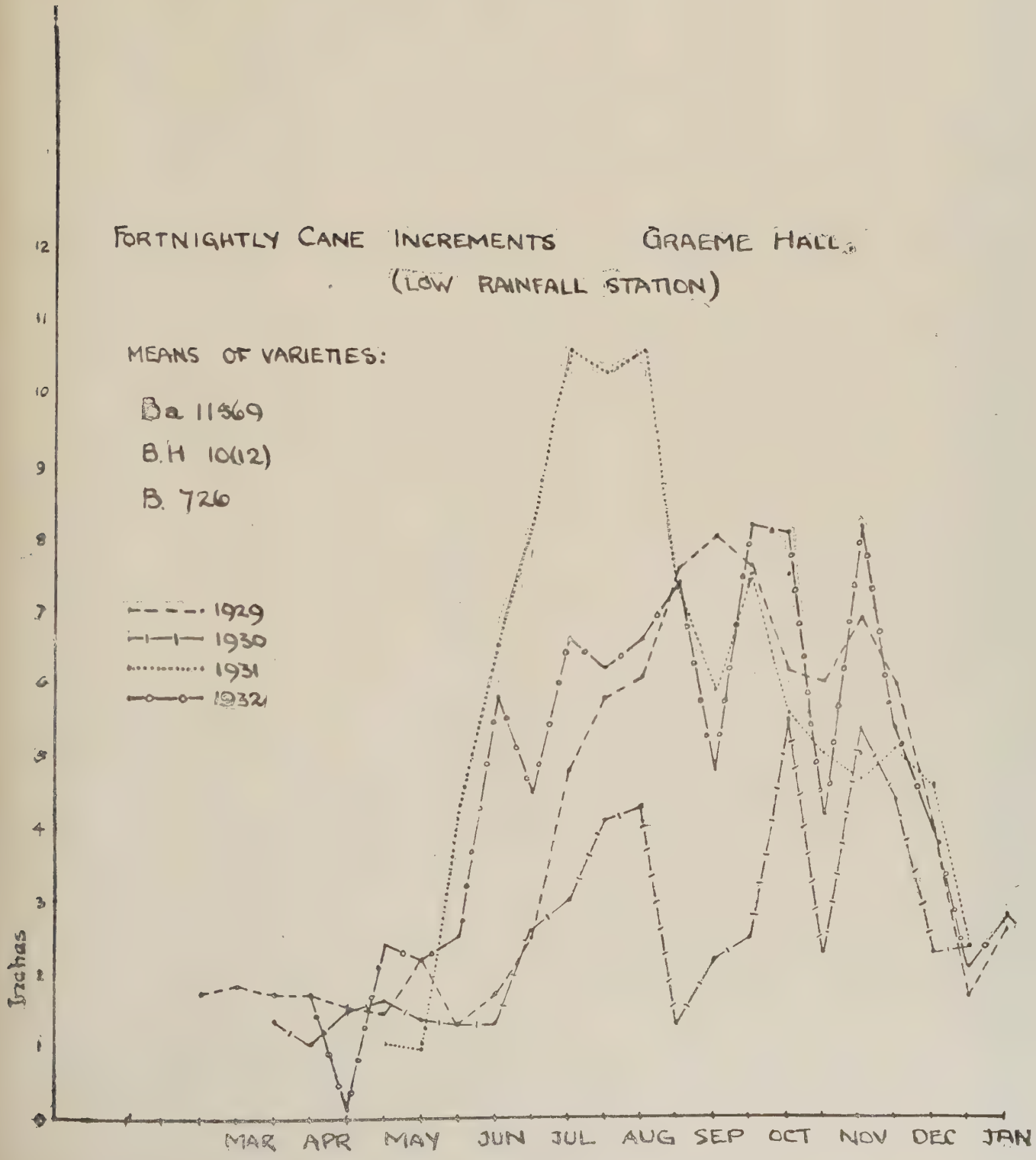

FORTNIGHTLY CANE INCREMENTS GRAEME HALL.
(LOW RAINFALL STATION)
MEANS OF VARIETIES:
Ba 11569
B.H 10(12)
B. 726
1929
1930
1931
1932
Inches
0
1
2
3
4
5
6
7
8
9
10
11
12
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XVI.

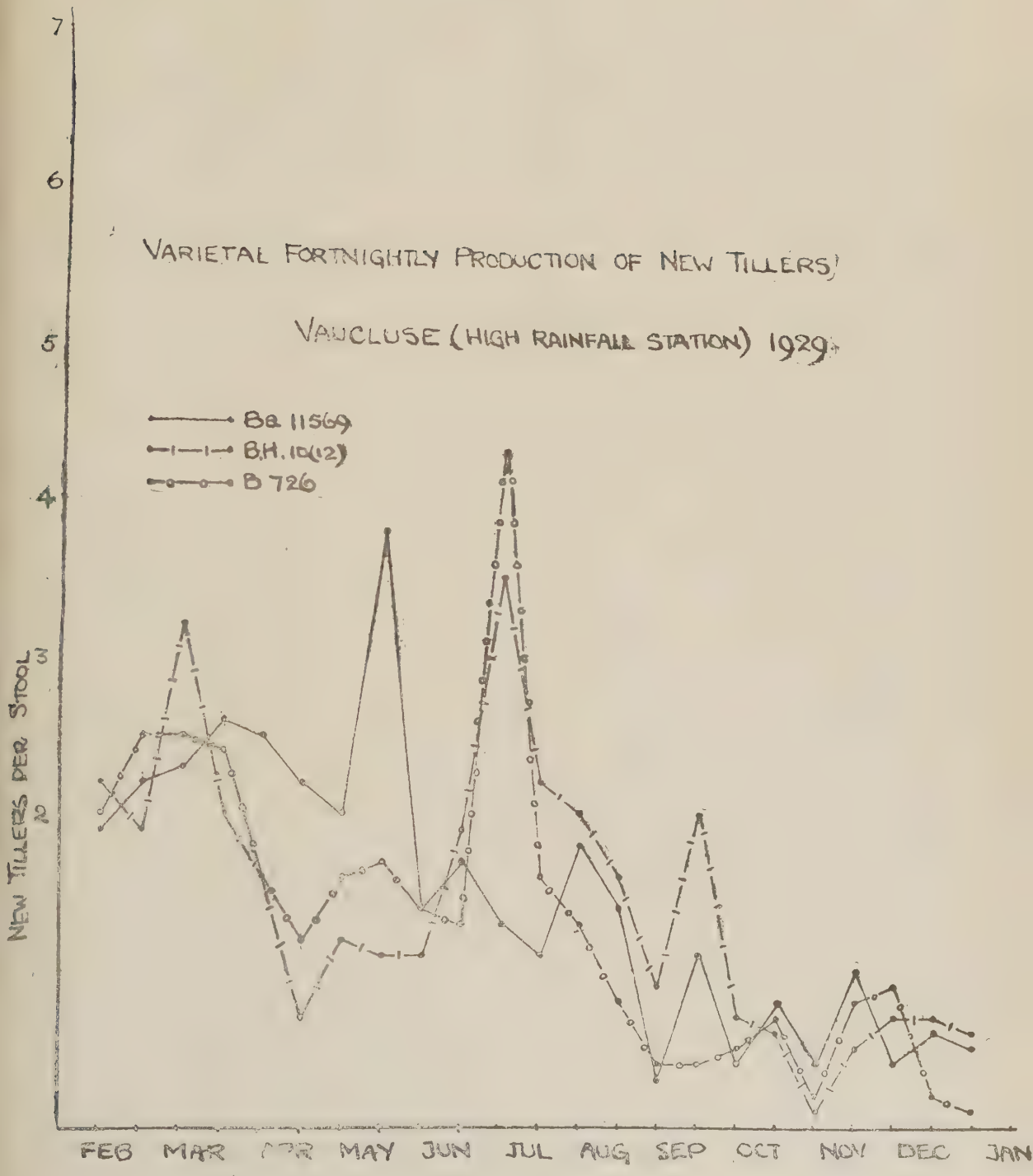

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS)
VAUCLUSE (HIGH RAINFALL STATION) 1929.
Bc 11569
B.H. 10(12)
B 726
NEW TILLERS PER STOOL
7
6
5
4
3
2
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XVII.

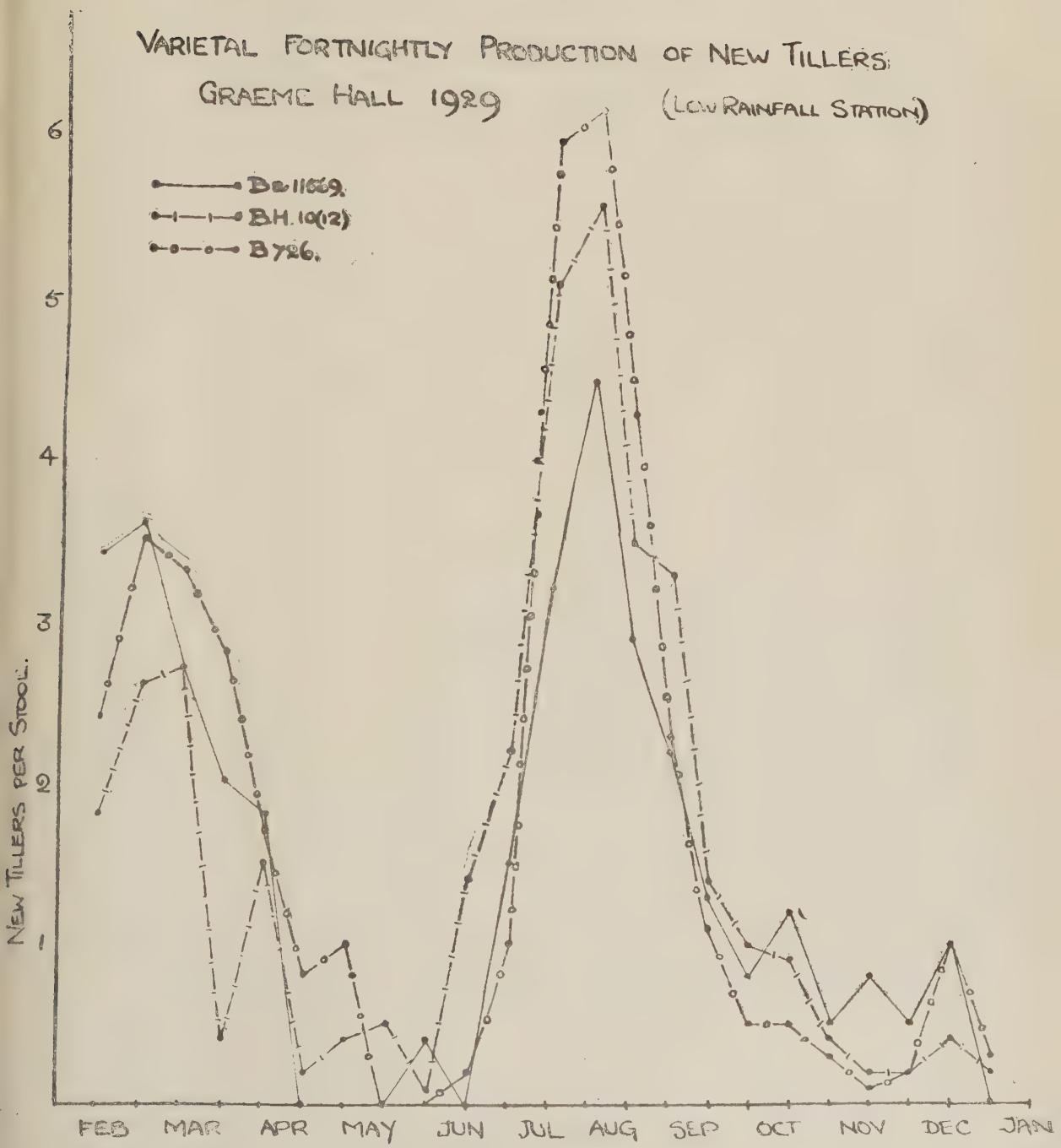

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS:
GRAEME HALL 1929
(LOW RAINFALL STATION)
B. 11(69).
B.H. 10(12)
B 726.
NEW TILLERS PER STOOL.
0
1
2
3
4
5
6
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XVIII.

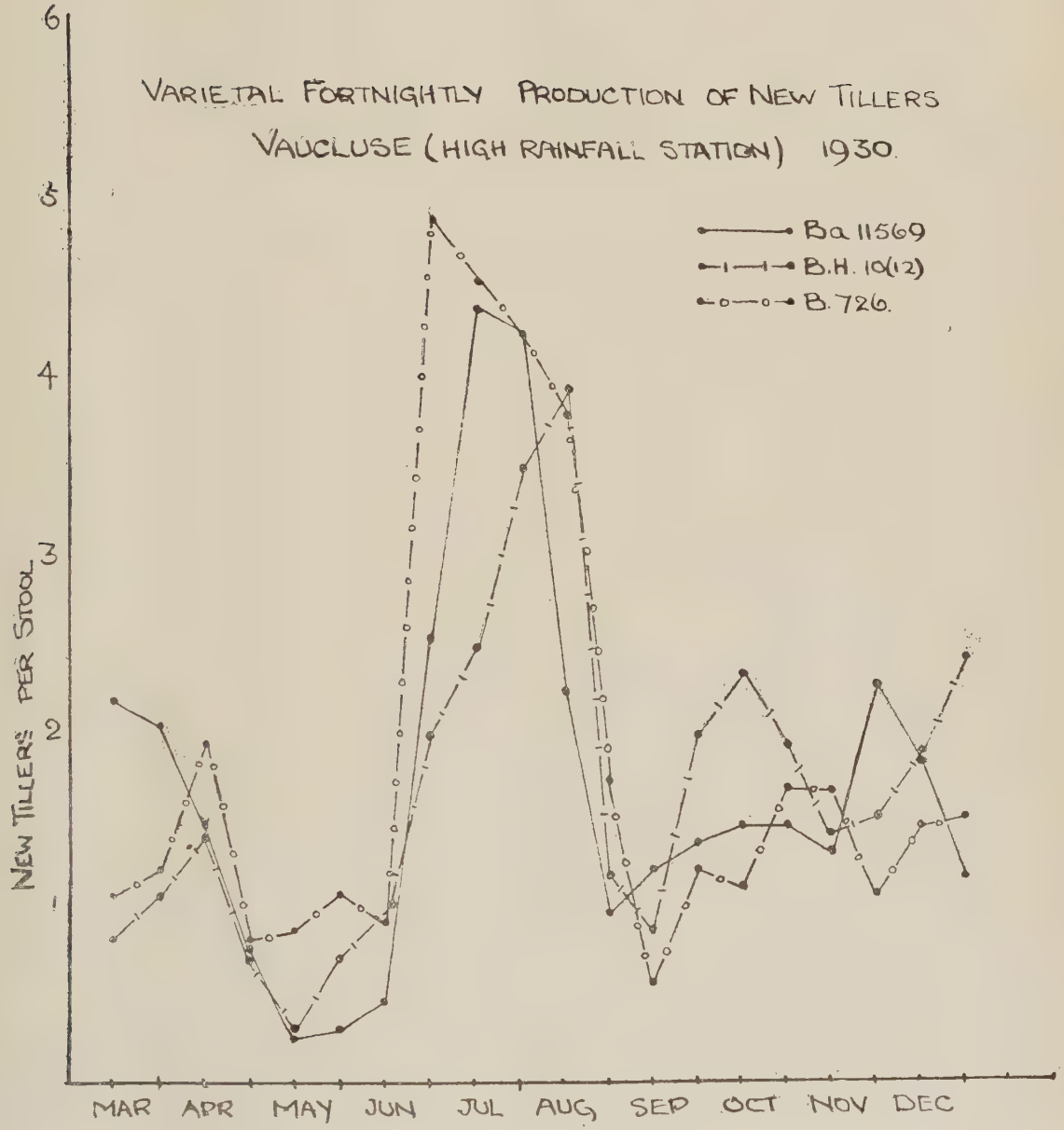

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS
VAUCLUSE (HIGH RAINFALL STATION) 1930.
Ba 11569
B.H. 10(12)
B. 726.
NEW TILLERS PER STOOL
6
5
4
3
2
1
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. XIX.

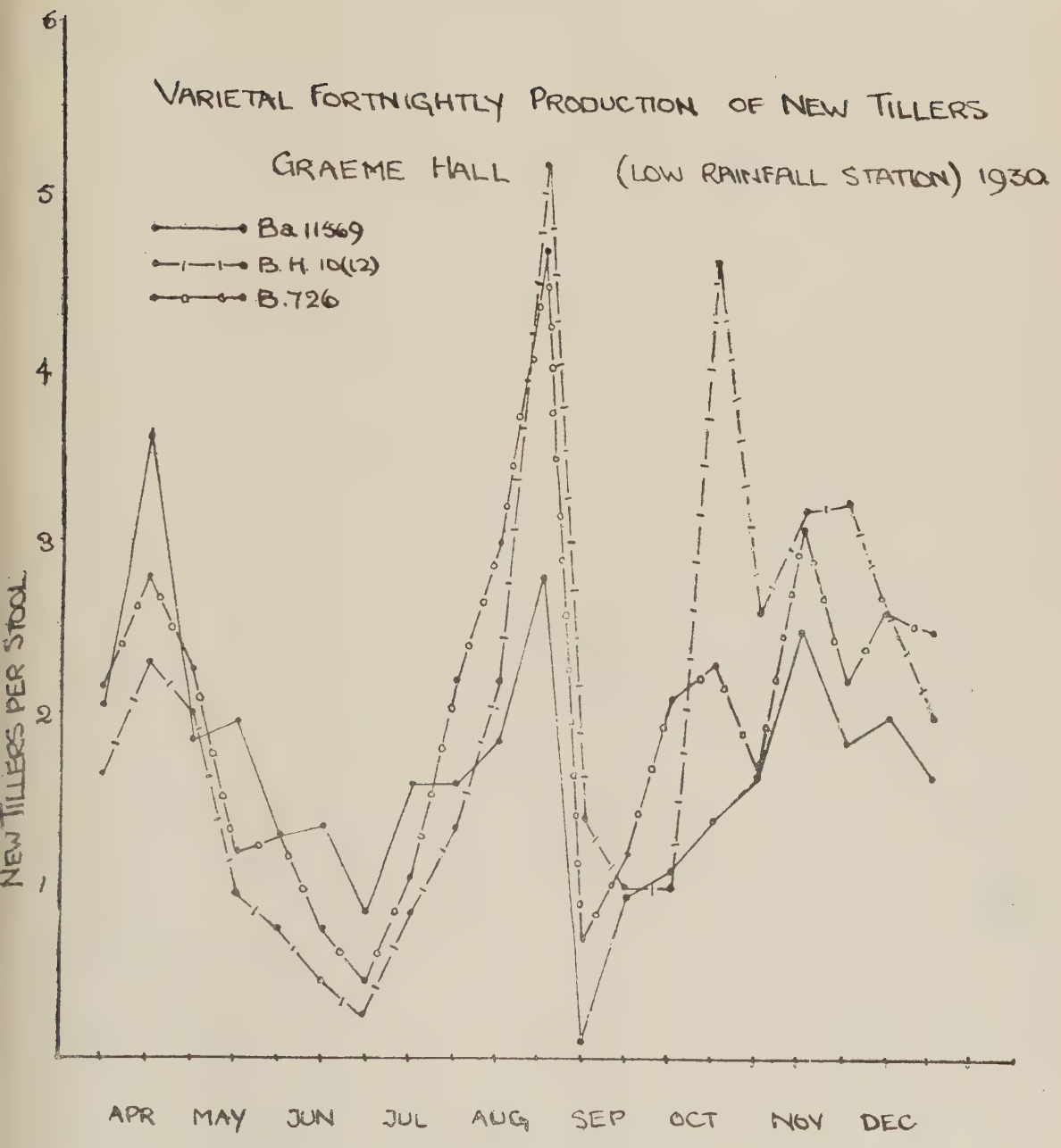

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS
GRAEME HALL (LOW RAINFALL STATION) 1930
Ba 11569
B.H. 10(12)
B.726
NEW TILLERS PER STOOL
6
5
4
3
2
1
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIG. XX.

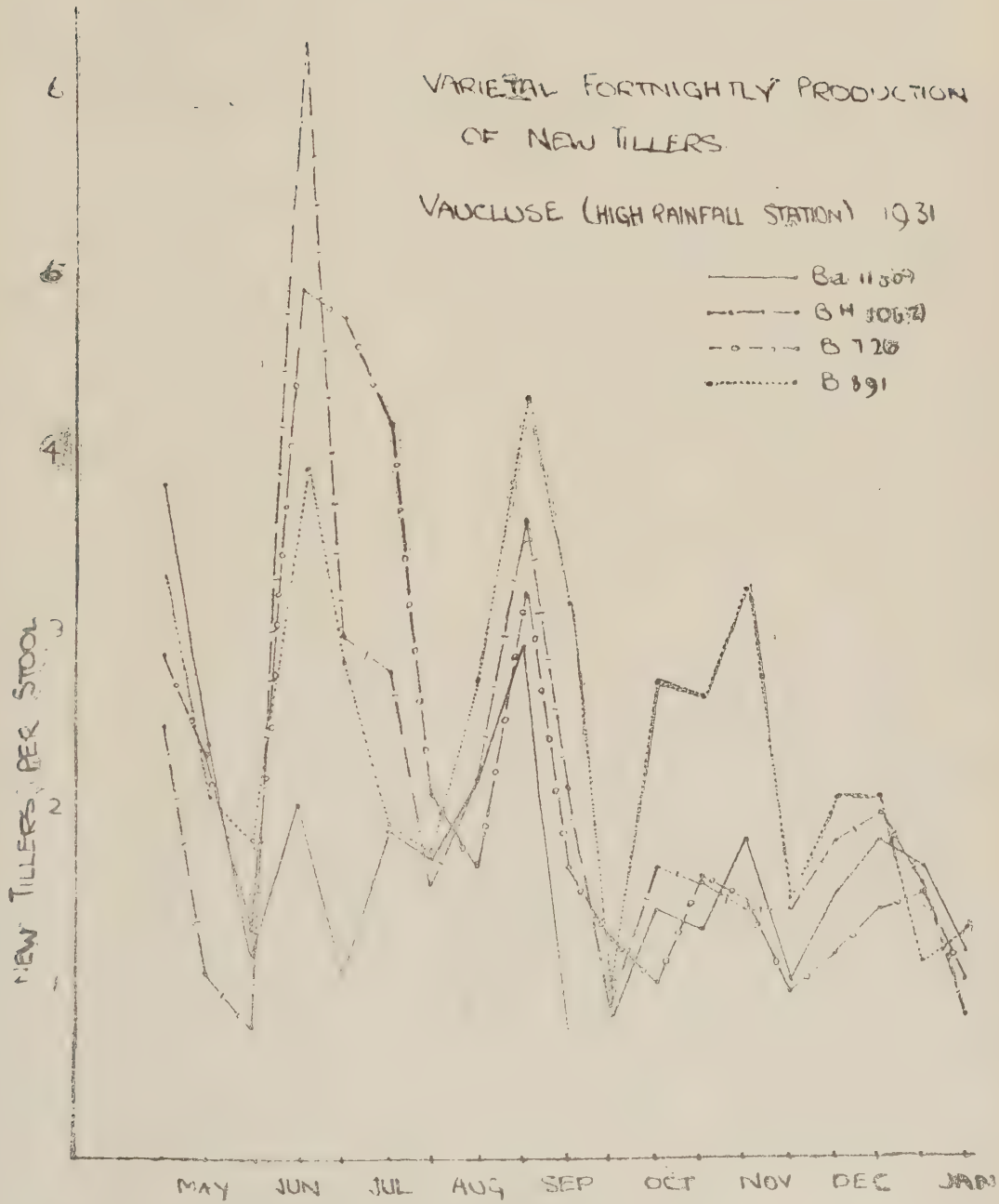

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS
VAUCLUSE (HIGH RAINFALL STATION) 1931
Ba 11509
B H 10674
B 7126
B 891
NEW TILLERS PER STOOL
6
5
4
3
2
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XXI.

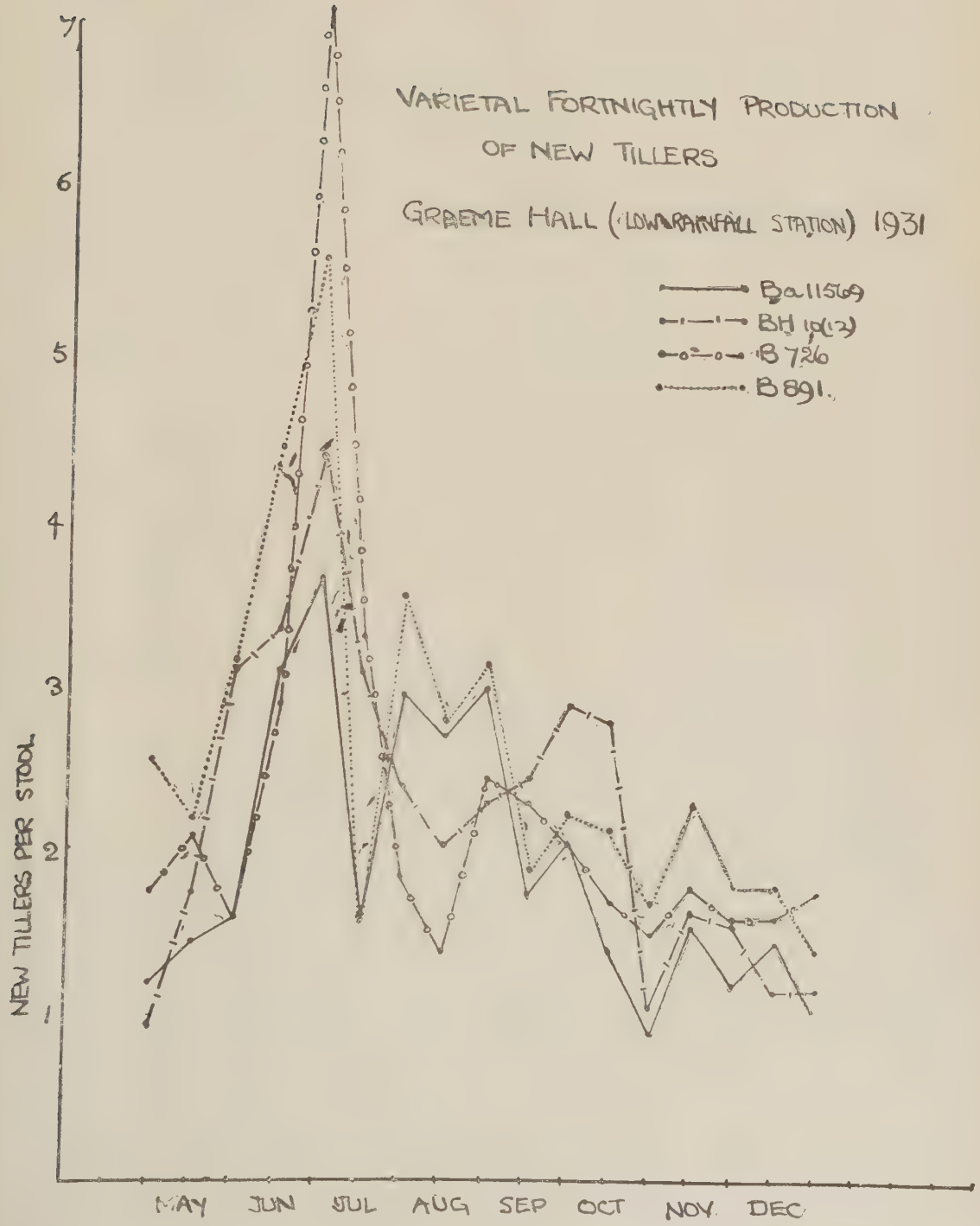

VARIETAL FORTNIGHTLY PRODUCTION
OF NEW TILLERS
GRAEME HALL (LOW RAINFALL STATION) 1931
Ba 11569
BH 10(12)
B 726
B 891.
NEW TILLERS PER STOOL
7
6
5
4
3
2
1
MAY
JUN
JUL
AUG
SEP
OCT
NOV.
DEC

FIG. XXII.

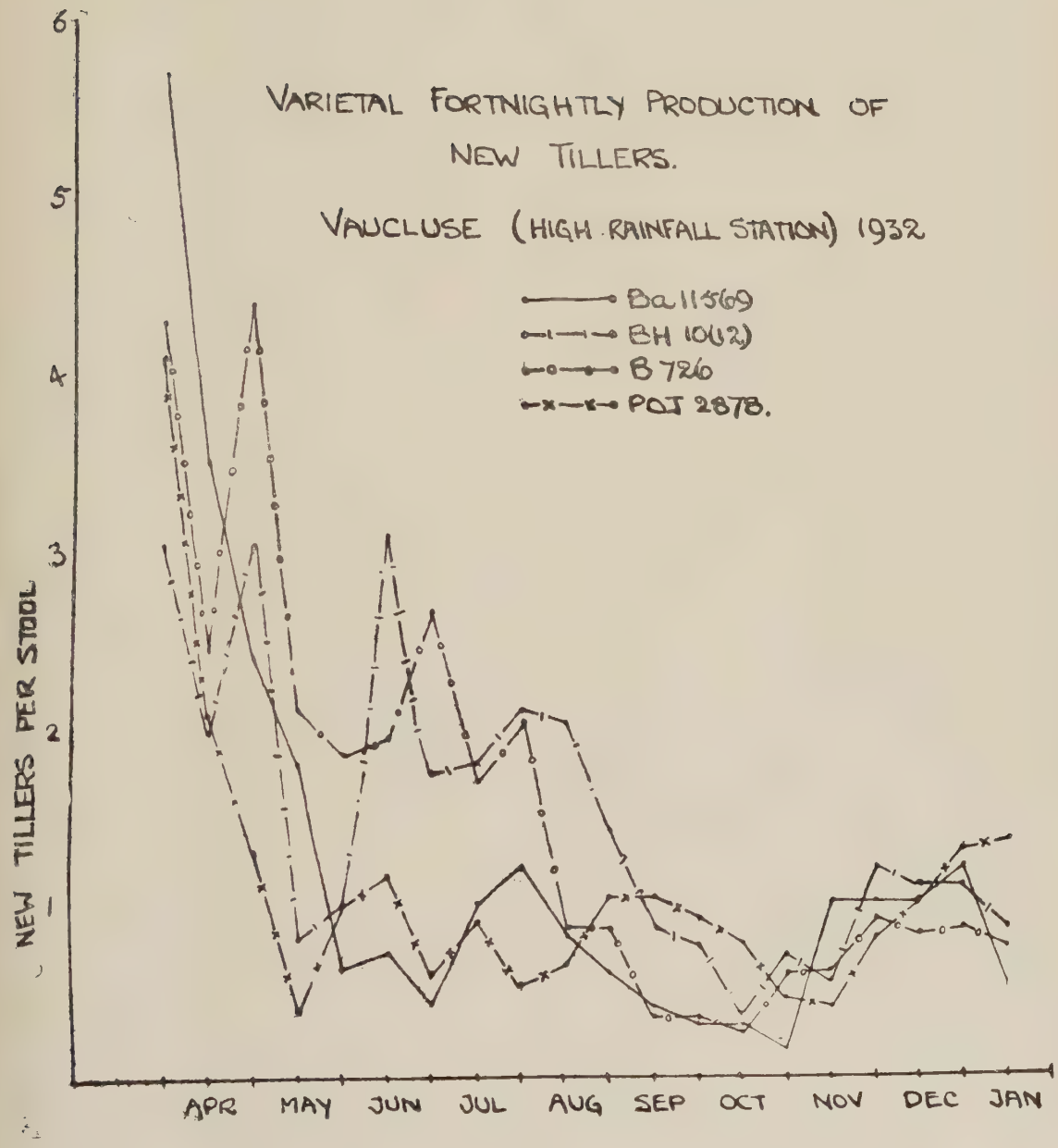

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS.
VAUCLUSE (HIGH RAINFALL STATION) 1932
Ba 11569
BH 10(12)
B 726
POJ 2878.
NEW TILLERS PER STOOL
6
5
4
3
2
1
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XXIII.

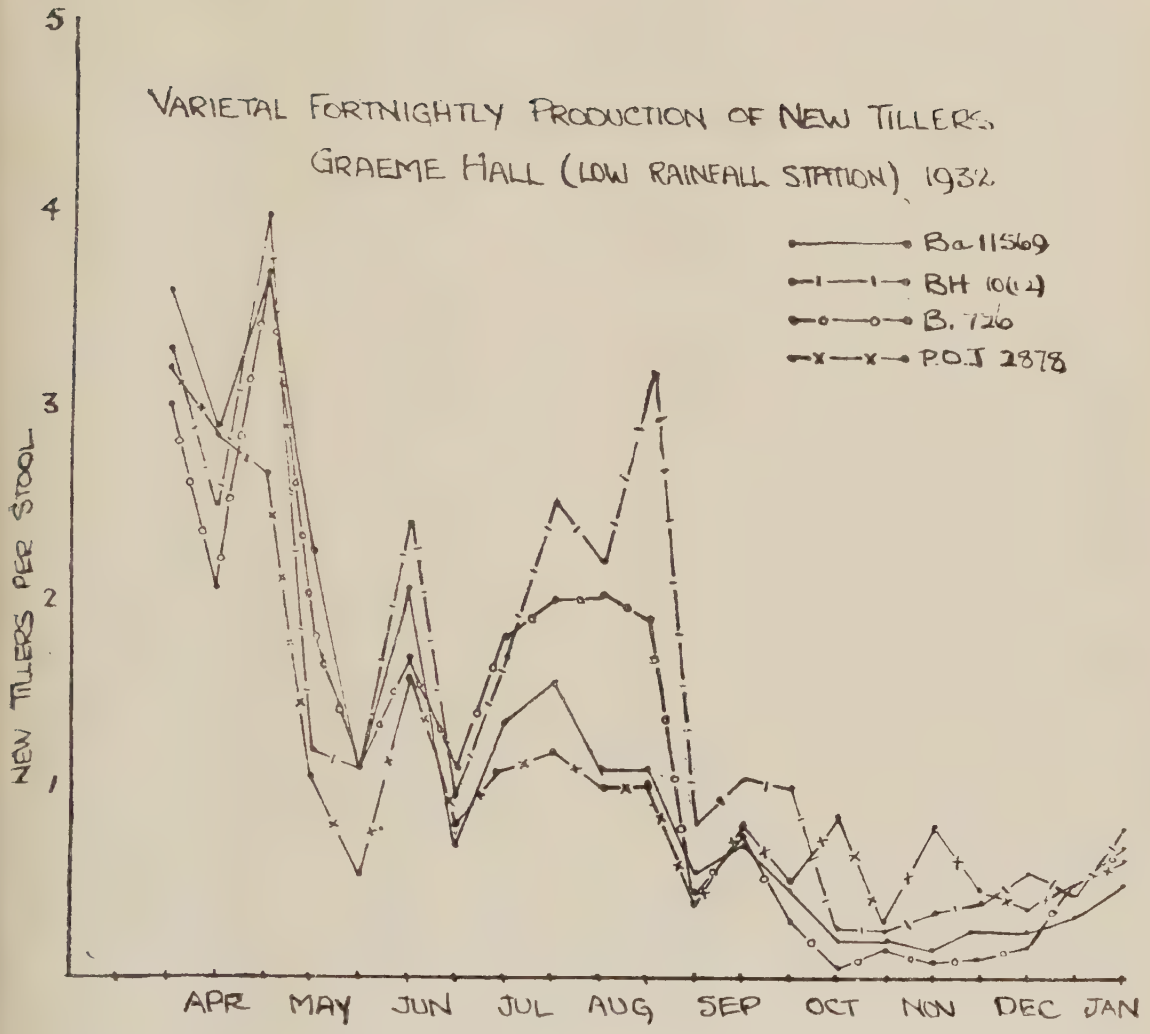

VARIETAL FORTNIGHTLY PRODUCTION OF NEW TILLERS.
GRAEME HALL (LOW RAINFALL STATION) 1932.
Ba 11569
BH 10(4)
B. 726
P.O.J 2878
NEW TILLERS PER STOOL
5
4
3
2
1
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XXIV.

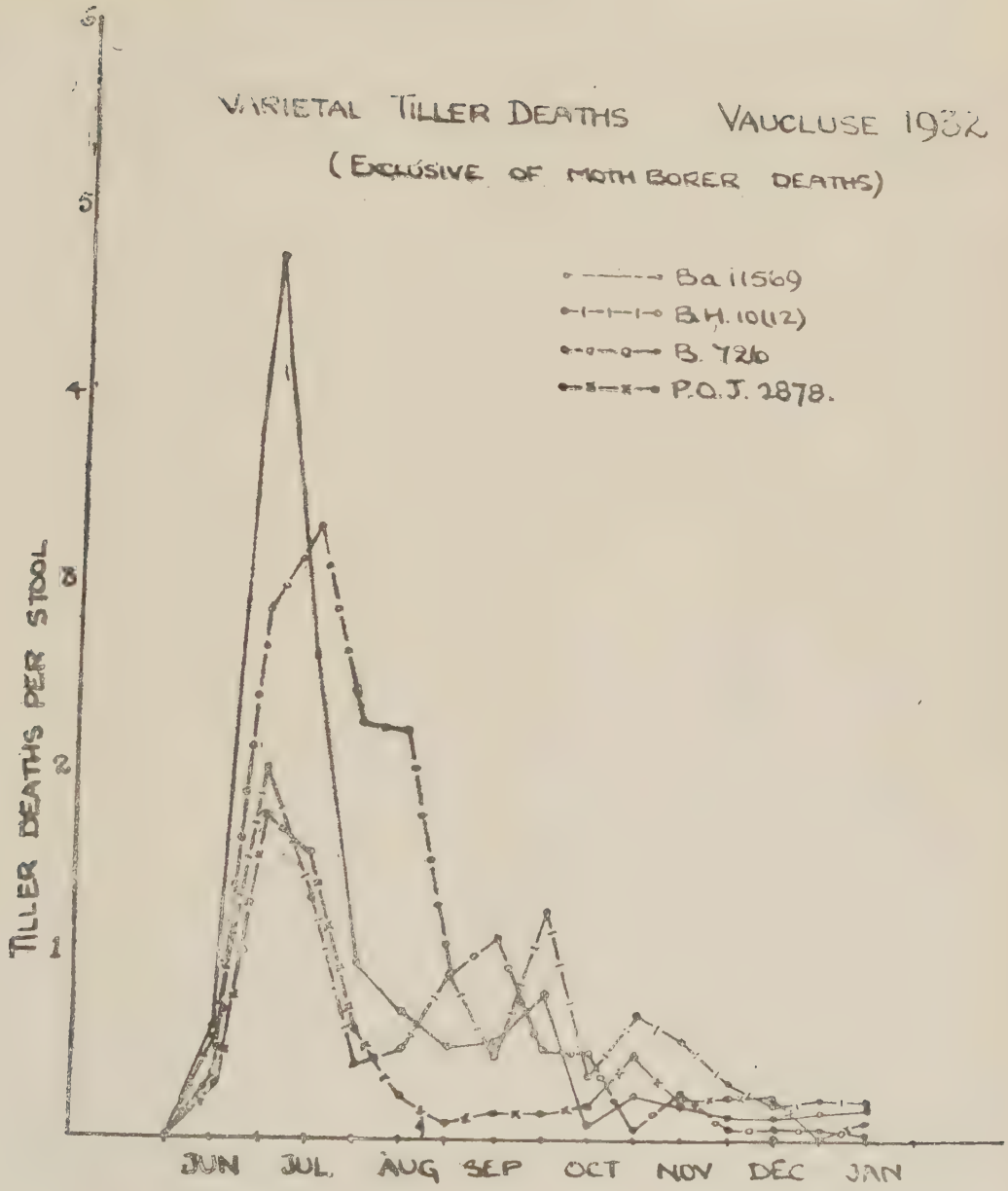

VARIETAL TILLER DEATHS VAUCLUSE 1932
(EXCLUSIVE OF MOTH BORER DEATHS)
Ba 11569
B.H. 10(12)
B. 726
P.O.J. 2878.
TILLER DEATHS PER STOOL
1
2
3
4
5
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XXV.

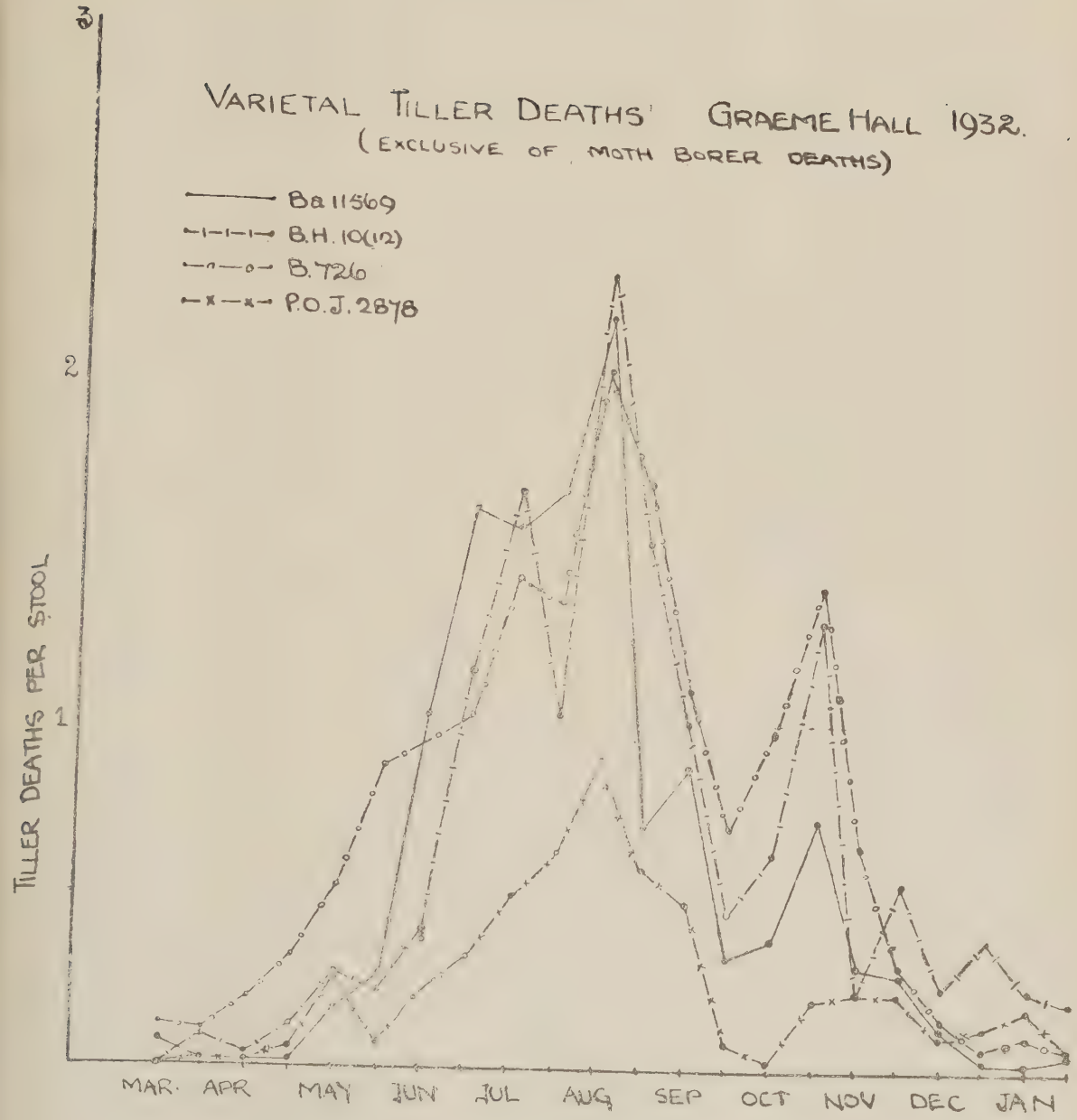

VARIETAL TILLER DEATHS' GRAEME HALL 1932.
(EXCLUSIVE OF MOTH BORER DEATHS)
Ba 11569
B.H. 10(12)
B.7216
P.O.J. 2878
TILLER DEATHS PER STOOL
3
2
1
MAR. APR MAY JUN JUL AUG SEP OCT NOV DEC JAN

FIG. XXVI.

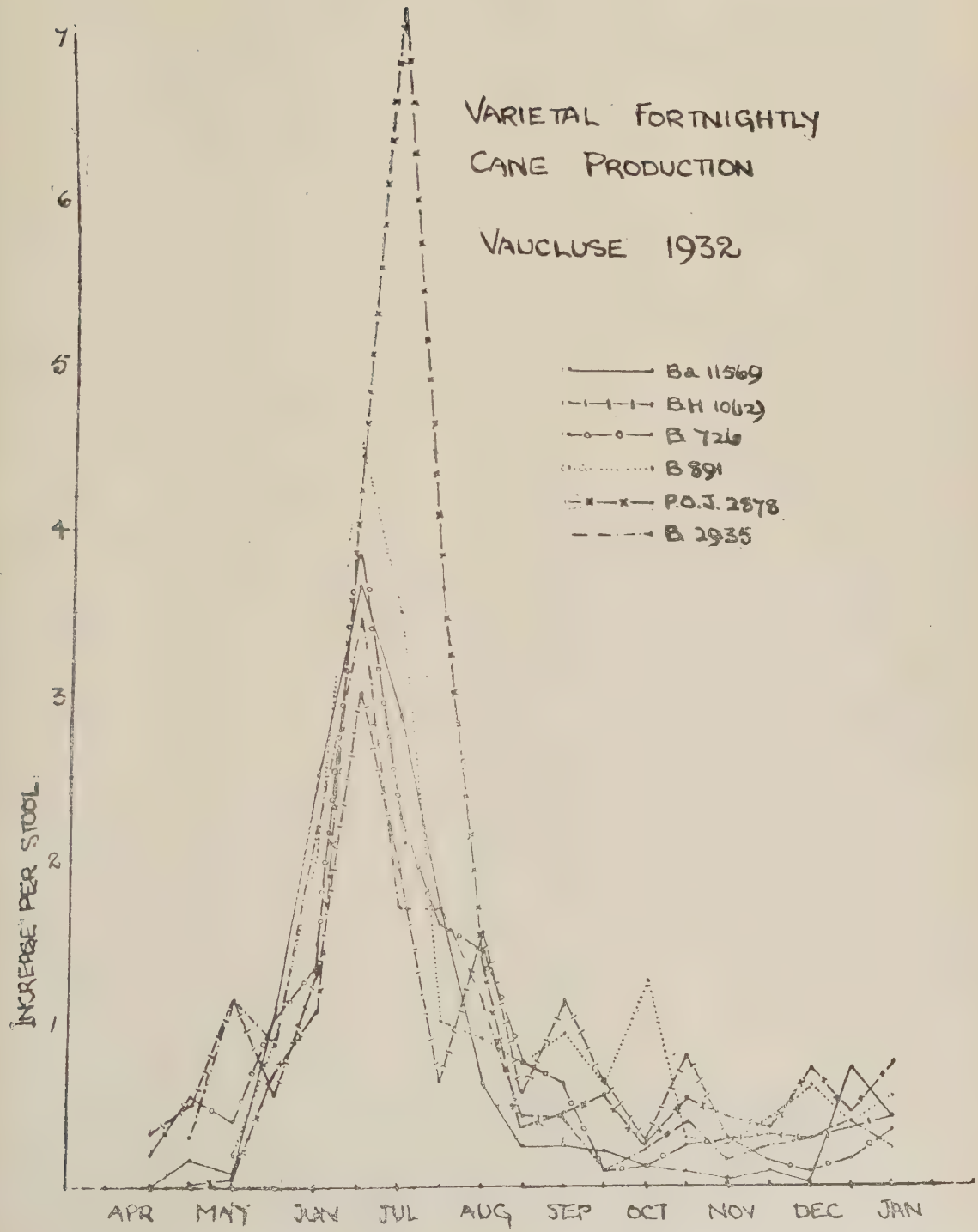

VARIETAL FORTNIGHTLY
CANE PRODUCTION
VAUCLUSE 1932
Ba 11569
B.H 10(12)
B 7266
B 891
P.O.J. 2878
B 2935
INCREASE PER STOOL
1
2
3
4
5
6
7
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XXVII.

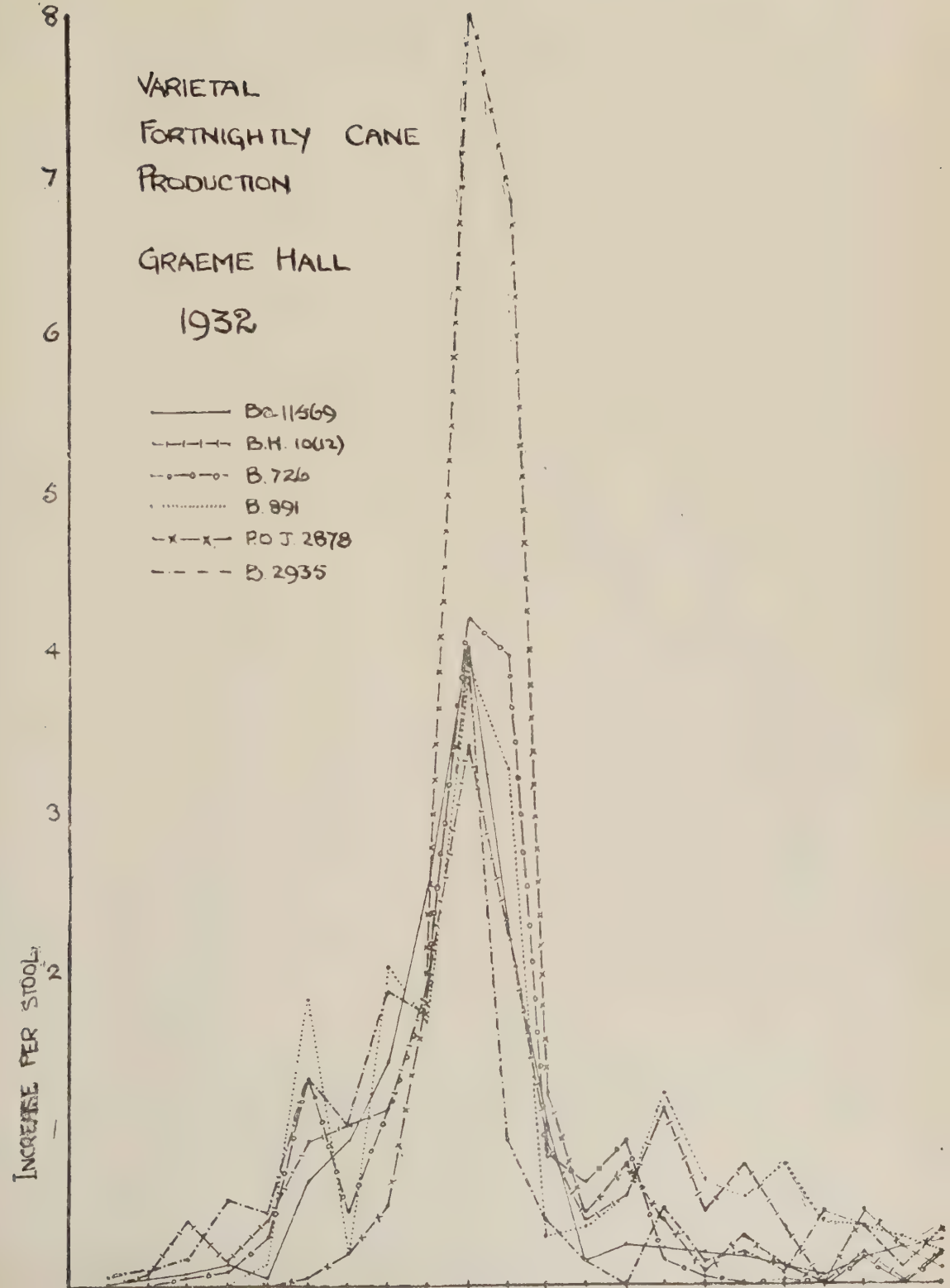

VARIETAL
FORTNIGHTLY CANE
PRODUCTION
GRAEME HALL
1932
Bc 11569
B.H. 10(12)
B. 726
B. 891
P.O.J. 2878
B. 2935
INCREASE PER STOOL.
8
7
6
5
4
3
2
1

FIG. XXVIII.

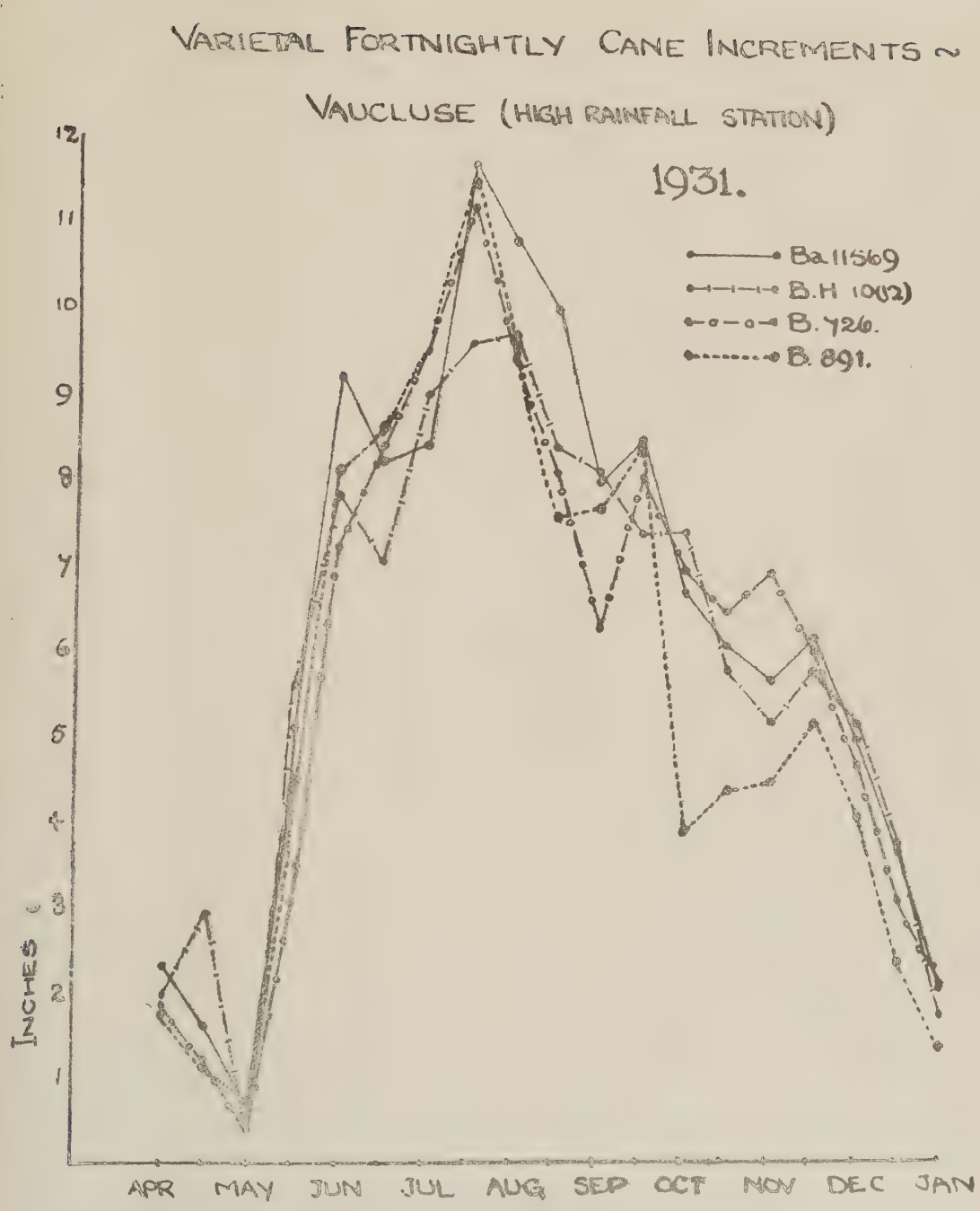
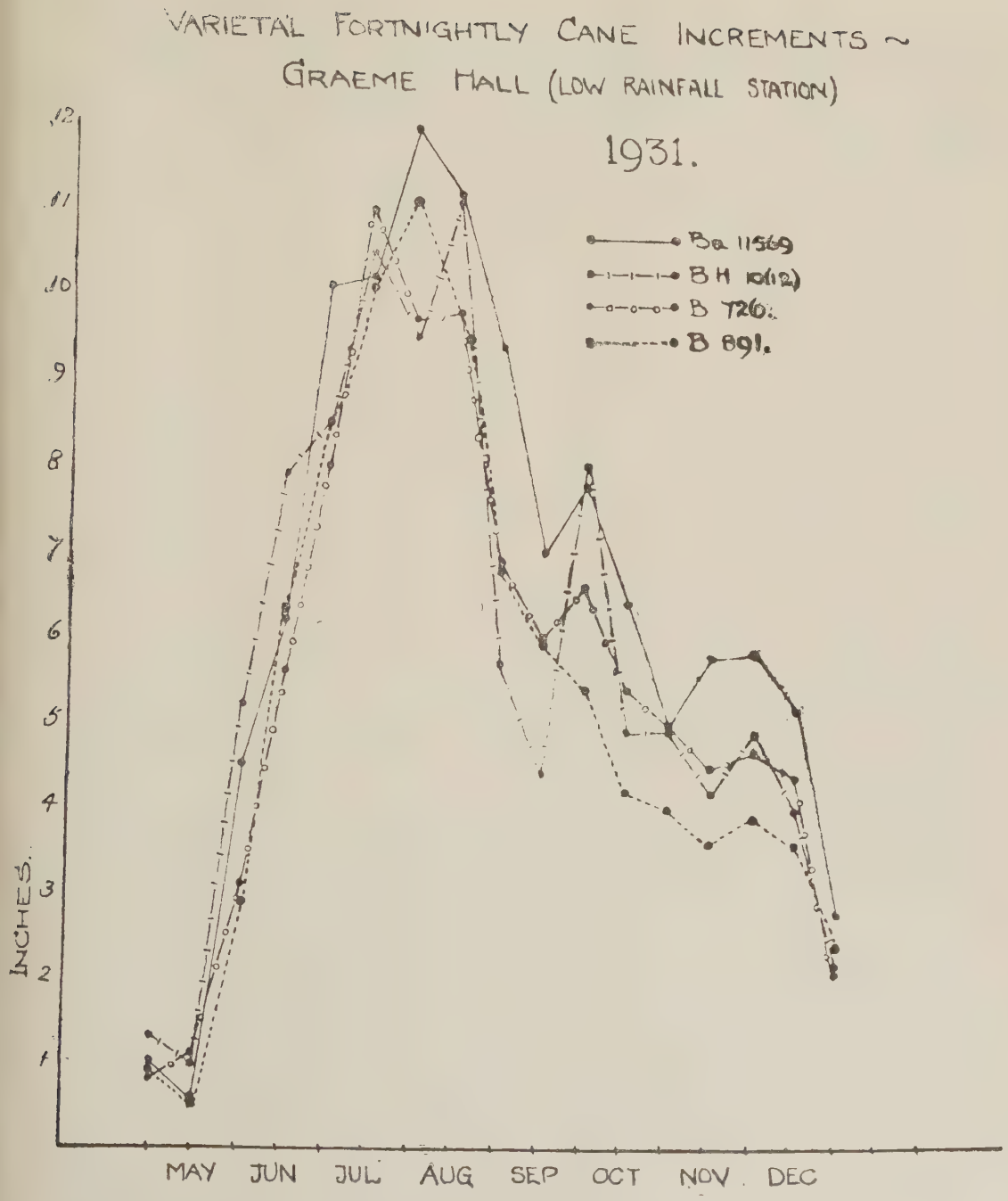

VARIETAL FORTNIGHTLY CANE INCREMENTS ~
VAUCLUSE (HIGH RAINFALL STATION)
1931.
Ba.11569
B.H 10(12)
B.726.
B.891.
INCHES
12
11
10
9
8
7
6
5
4
3
2
1
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN

FIG. XXIX.


VARIETAL FORTNIGHTLY CANE INCREMENTS ~
GRAEME HALL (LOW RAINFALL STATION)
1931.
Ba 11569
B H 10(12)
B 1260.
B 891.
INCHES.
12
11
10
9
8
7
6
5
4
3
2
1
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

A CONTRIBUTION TOWARDS THE SOLUTION OF THE PROBLEM OF CONTROL OF DIATRAEA SACCHARALIS IN CANE THROUGH A MATHEMATICAL EVALUATION OF THE REAL MORTALITY OF D. SACCHARALIS DUE TO EGG PARASITES, EGG PREDATORS, NATURAL LARVAL MORTALITY, LARVAL PARASITISM AND OTHER FACTORS.

By R. W. E. TUCKER, M.A., B.Ed.

It is a recognised fact that *Diatraea saccharalis* is the most universal and the most economically serious of the sugar cane pests in the West Indies and American areas. In the various countries in which it occurs, it is attacked by numerous parasites, from egg parasites to larval and pupal parasites, and is subject in its young larval stages to a considerable natural or general mortality. These various mortality factors are not all present together or to the same degrees, in the various *D. saccharalis* areas. Two, however, are common to practically all areas, namely *T. minutum* and early larval mortality. Other factors such as larval or pupal parasites are either totally absent in some areas, or different in type and effectiveness in others.

The question therefore inevitably arises as to the exact or real value of these various factors when present, and their value if multiplied by laboratory methods as *T. minutum* is, or introduced from one *D. saccharalis* area to another as are the larval parasites *Lixophaga diatraea* and *Paratheresia claripalpis* both these methods being current contributions to the solution of the problem of economic control of *D. saccharalis* in the West Indian and American areas. (1) and (4).

The solution of this problem can be advanced by the full application of the formulae (quoted below) given by Dr. W. R. Thompson in Parasitology, Vol. XX, No. 1, pp. 98—105, whereby the real effect of various mortality factors which exist in any area can be evaluated, if their apparent field value is satisfactorily determined, and their sum total of real destruction of pest population ascertained in a manner which permits reasonable comparison.

Not only does this enable the real value of increasing the effectiveness of *T. minutum* as practised in Barbados, Louisiana and Peru† to be determined, but it enables a reasonable idea to be arrived at of the end result likely to be obtained by introducing into *Diatraea* areas larval parasites such as *Lixophaga* or *Paratheresia* provided they become permanently established in their new environment, and provided they maintain as a general average at least the rate of parasitism given in the numerical examples worked out in the following pages.

Following Dr. Thompson's work then, if A.B.C.D. etc. represent the *real* destruction and a.b.c.d. the *apparent* destruction of *total initial population*,

† *T. australicum* and *T. japonicum* are now being used in Formosa to control Pyralid borers in canes.

due to mortality factors F1, F2, F3, F4 etc., then A = a, B = (1–a)b, C = (1–a) (1–b)c, D = (1–a) (1–b) (1–c)d. The difference between real destruction and apparent destruction will then be evident from the following table.

Factor.	Apparent Destruction.	Real Destruction.
F1	a	a
F2	b	(1–a) b
F3	c	(1–a) (1–b)c
F4	d	(1–a) (1–b) (1–c)d

As stated by Dr. Thompson, "the difference between apparent and real "destruction effected by a given factor may thus be enormous—the importance "of this point depends on the fact that the mortality produced by the control-"ling factors as determined by the working entomologist is *practically always* "the apparent mortality, the only exception being in studies on the effect of egg "parasites."

In the case of egg parasites it is therefore evident that when egg deposition is taken as *initial population*, then the apparent destruction is also the real destruction when the parasite is the first mortality factor.

It would appear that total initial population *is* usually taken to be total egg deposition, but the proviso must be added that it is egg deposition at the period or time for which the values of the mortality factors have been determined and for that period only. In fact no other interpretation seems possible for *D. saccharalis*, because total initial egg population fluctuates widely and varies with the time of year. Mortality factors also vary considerably according to the time of year but it is perfectly possible to take adequate samples of egg deposition at any period for which mortality factors are determined, and so ascertain with reasonable accuracy the total initial population of which the real mortality is being determined.

As it happens, however, the above formulae are not concerned with the *extent* of total initial population: the latter factor would only operate were it desired to estimate the rapidity of control, or probable time which would elapse before full control was reached.

On p. 101 *loc. cit.* Dr. Thompson considers the "Effects of the disappearance "of general and individualised factors from controlling complexes of various "types" having previously defined "general factors" as being those such as early larval mortality, and destruction due to agricultural practices etc. and "individualised factors" as those such as egg parasites or larval and pupal parasites.

On page 104 *loc. cit.* a numerical example is given of a case in which we have the disappearance of factors of either or both types from a complex including both.

D. saccharalis and its controlling factors is such a case and by substituting the known values of the various mortality factors determined for Barbados in

the example on page 104 (reproduced below) we can arrive at an evaluation of the real mortality produced by the general and individualised factors in the *D. saccharalis* complex.

In Dr. Thompson's words "Let us suppose that we have an insect depositing "100 eggs, for whose control a 98 per cent. parasitism* is required, and that it "is brought about by a succession of factors as follows:—

Stage	Factor.	Apparent mortality.	Real mortality.
		%	%
Eggs at deposition ..	(F1) †Sterility	(a)† 5.0	a 5.00
Eggs after deposition ..	(F2) Egg parasites.	(b) 10.0	(1-a) b 9.50
Young larvae ..	(F3) Intrinsic factors.	(c) 80.0	(1-a) (1-b) c 68.40
Mature larvae..	(F4) Larval parasites.	(d) 60.0	(1-a) (1-b) (1-c) d 10.26
Mature larvae..	(F5) Agricultural factors.	(e) 30.0	(1-a) (1-b) (1-c) (1-d) e 2.05
Pupae ..	(F6) Pupal parasites.	(f) 10.0	(1-a) (1-b) (1-c) (1-d) (1-e) f 0.47
Adults ..	(F7) Meteorological factors.	(g) 54.86	(1-a) (1-b) (1-c) (1-d) (1-e) (1-f) g 2.30
			97.98

"In this series the factors F1, F3, F5 and F7 are general and independent "factors, while F2, F4 and F6 are individualised and dependent factors.

"Suppose now that factors F2, F4 and F6 disappear. The total destruction "produced by the remaining factors will then be given by the equation

$$D = a + (1-a)\,c + \left\{1-[a + (1-a)c]\right\} e + [$$

$$+ [1- \left\{a + (1-a)\,c + (1-[a + (1-a)\,c]\,)\,e\right\}]\,g$$

=94.0 per cent. approximately.

* This should be, apparently, total real mortality, not parasitism.

† The writer has taken the liberty of inserting the corresponding symbols into Dr. Thompson's numerical example for the guidance of those who have not the advantage of referring to his paper on the subject.

"Thus the absence of parasites causing a 10.0 per cent. apparent mortality "in the egg stage, a 60.0 per cent. apparent mortality in the larval stage and a "10.0 per cent. (apparent) mortality in the pupal stage *i.e.*, an 80 per cent. "total apparent mortality, would have a much less disastrous effect than might "be supposed. The total destruction would fall only 4.0 per cent. *The absence "of the parasites would allow the escape for reproduction of only two additional "females per hundred.** Since such an enormous fluctuation in the apparent "mortality has so little effect, it is evident that slight fluctuations will ordinarily "be of no importance."

This has a direct bearing on the *Diatraea* problem, in that as pointed out, the factors F2 and F3 are almost universally present in the *Diatraea* complex, and probably also F1; and in Barbados at least, an additional individualised factor in destruction of eggs by predators. It would appear obvious therefore that the presence or absence of an F4 mortality due to larval parasites will not cause a great alteration in the final real mortality figures.

This must not be interpreted as meaning that larval parasites are considered as useless; this is neither stated nor implied. It does mean in the writer's opinion that small fluctuations in the final real mortality, especially near the critical 98% real mortality total, are more effective in final field infestation results than the figures indicating the fluctuations would lead one to suppose.

Thus, in the above italicised example, the escape for reproduction of only "two additional females per hundred" (*eggs* not females), would mean, in the case of *D. saccharalis* and its continuous nightly deposition of eggs throughout the greater part of the year, a very large increase in borer damage. Whether *Diatraea* egg deposition exceeds a million and a half per acre per brief period as stated or indicated in current literature (2) or is nearer to the maximum of 27,000 eggs per acre per month determined in 1933 in Barbados, the escape of 4 extra effective borers for each 100 eggs laid, would rapidly increase the number of bored canes and joints to a serious extent at the end of 11 or 12 months, and the production from each 4 additional larvae of 2 additional egg laying females from every 100 *Diatraea* eggs laid throughout the year would undoubtedly result in a rise in pest population to very damaging proportions. Differences of much less than 4% in many of the total real mortalities of *Diatraea* complexes examined below are considered by the writer to produce considerable field results.

In the following pages, the foregoing formulae and reasoning will be applied to the various complexes that actually exist, and that it is intended to bring about in Barbados, by the introduction of larval parasites; and also to complexes which would exist were a high larval mortality of 97% average to apply in either of the above cases in place of the values for this F4 factor which have been determined for Barbados and which are used in Table I. A 97% average is taken, as it is definitely stated in current literature (1) that early larval mortality ranges from 92% to 100% with *an average of* 97%.

Before proceeding further, the interpretation placed by the writer on the term "early larval mortality" needs clear definition. For some considerable time

* per hundred eggs.

contemporary writers have considered that there must be a very high early larval mortality among newly hatched *Diatraea* larvae, and this mortality has been stated to be over 90%. Thus Dr. Myers states (6) "Over 90 per cent. of the young "larvae of *Diatraea* perish before they enter the stalk, and thus before they have "committed any damage. Similar figures have been published for the European "Corn Borer (*Pyrausta nubilalis*). Thus over 90 per cent. of the young larvae "which are killed in the egg by the egg parasites would have died in any case."

At a much later date, Mr. Box (1) raises this figure to a definite determination of "from 92 to 100 per cent. with an average of 97 per cent." normal intrinsic mortality among newly hatched larvae, which is considered to "swamp "any possible benefits that might be due to the action of egg parasites alone."

No period limit is given for these mortality figures and the inference is that this mortality rate is considered to be permanently operative.

It is moreover obvious from the above that early larval mortality is defined as that which occurs among newly hatched larvae before they enter the stalk and before they commit any damage.

Continuous observations made by the writer, however, have shown that subsequently to feeding on or penetrating into cane shoots many larvae still die from natural (i.e. not parasitic) causes, so that the final larval mortality figure is higher than the initial larval mortality. Therefore, as previously stated by the writer, early general larval mortality and final general larval mortality are quite different, and it is definitely possible for larvae to penetrate cane shoots and admit fungi or to reach and kill the growing point of a shoot i.e. to enter the stalk or commit damage, and still to die at a fairly early stage, and not to complete their full cycle of development.

The disappearance of such larvae therefore does not, strictly speaking, come under the definition of "early larval mortality" because they have lived long enough to damage cane tissue, possibly to a serious extent.

In the following calculations however the writer adopts the final larval mortality figures given in Table XI of Agric. J1., Vol. 2 No. 4 Dept Science and Agriculture, Barbados, 1934, for larvae which have been found alive in cane shoots and stalks each month from a known number of larvae hatching that month in a plot of 40 cane stools.

This is done for two reasons; in the first place because the records of *living larvae recovered each month from a known number of larvae hatching* in a plot of 40 cane stools have been definitely determined *for each month*, and secondly because by giving this extended scope to the term "early larval mortality" there is less possibility of subsequent differences of opinion arising.

It has been stated by the writer that *Diatraea* complexes change with the season and stage of cane growth, owing to definite changes caused thereby in the values of mortality factors, and owing to variable deposition of eggs. It is considered therefore that the *minimum* period over which the average value of

mortality factors can be determined, is one month; and that the *maximum* period over which these determined figures can be held to operate is also one month; this may be considered a somewhat arbitrary allocation, but is necessary and quite reasonable.

As two monthly periods have been chosen, namely June and September, in which mortality factors have been adequately determined (9) it is obvious that the application of the above changes of mortality factors in both months will bring about a series of complexes, real, intended and possible, which will be confusing at first.

Table I has therefore been drawn up to simplify matters, and if reference is made to it throughout, the various complexes will be easier to follow and to compare one with the other.

For further ease of reference, the conditions as in I. e., Table I, namely actual conditions in Barbados in June, 1933 during colonisation with *Trichogramma* are set out on the lines of Dr. Thompson's example as given on page 61. The various mortality factors are thus made clear, and future reference should be simplified.

Example I.e., Table I. Actual conditions in Barbados in June, 1933.

Stage.	Factor.		Apparent mortality.	Real mortality.
			%	%
Eggs at deposition ...	Sterility [1]	F1	2.0	2.0
Eggs after deposition	Egg parasites	F2	70.0	68.6
Eggs after deposition	Egg predators[2]	F3	22.0	6.47
Young larvae ...	General factors[2]	F4	89.5	20.52
Mature larvae ...	Larval parasites	F5	0	0
Mature larvae ...	Agricultural factors[3]	F6	0	0
Pupae	Pupal parasites	F7	0	0
Adults	General factors[4]	F8	15.0	0.36
				97.95

1. Sterility of *Diatraea* eggs is placed at 2% for the writer has in years of experience rarely seen dead or unhatched eggs which could definitely be assessed as sterile and it is considered that 2% amply covers egg mortality from this cause.

2. See Agric. Jour., Vol. 2, No. 4, Dept. Science and Agric., Barbados, 1934. The factors F3 and F4 have been determined over a period of one year only, and, though adequately determined by bi-weekly observations in several contiguous plots each of 40 cane stools, have not the same background of continuous observations that F2 has.

3. Agricultural factors causing death of larvae and pupae are nil in June; it is only in ripe canes reaped and milled in February—May that a large and catastrophic larval and pupal mortality occurs. Mortality due to fungus *Cordyceps* is so small in Barbados that it is not computed here. Pupal parasites are totally absent.

4. Natural, general or intrinsic mortality factors affecting adult *Diatraea* in canefields in Barbados have not been determined, but are considered by the writer to be low *prior to egg laying* and are assessed at an absolute maximum of 15% apparent mortality.

Determination of Real Mortality in Diatraea Complexes.

TABLE I.

I. Average Conditions for the Month of June, 1933.

	F. 1.	F.2.	F.3.	F.4.	F.5.	F.6.	F.7.	F.8.	Total Real mortality.
	%	%	%	%	%	%	%	%	%
a.	2	33[1]	22	89.5[5]	0	0	0	15	95.41
b.	2	33	22	89.5	35	0	0	15	97.02
c.	2	33	22	97.0[6]	0	0	0	15	98.68
d.	2	33	22	97.0	35	0	0	15	99.13
e.	2	70[2]	22[3]	89.5	0	0	0	15	97.95
f.	2	70	22	89.5	35	0	0	15	98.66
g.	2	70	22	97.0	0	0	0	15	99 41
h.	2	70	22	97·0	35	0	0	15	99.61

TABLE I. (*Continued.*)

II. Average Conditions for the Month of September, 1933.

	F.1.	F.2.	F.3.	F.4.	F.5.	F.6.	F.7.	F.8.	Total Real mortality.
	%	%	%	%	%	%	%	%	%
a.	2	52[1]	4[4]	16[5]	0	0	0	15	67·74
b.	2	52	4	16	35	0	0	15	79.01
c.	2	52	4	97[6]	0	0	0	15	98.79
d.	2	52	4	97	35	0	0	15	99.19
e.	2	90[2]	4	16	0	0	0	15	93.27
f.	2	90	4	16	35	0	0	15	95.62
g.	2	90	4	97	0	0	0	15	99.75
h.	2	90	4	97	35	0	0	15	99.83

References to Table 1,—*continued.*

[1] Normal parasitism by *Trichogramma.*

[2] Colonised parasitism by *Trichogramma*; both figures determined by adequate field work for their respective months. See Agric. Jour. Dept. Science and Agric., Barbados, Vol. 2, No. 4, 1934.

[3] The actual field determination of F3 was 18.28%; when F2 was 70%; this correction can be made if desired.

[4] F3 in September is apparently confined to the work of Pscoid larvae, for the earth inhabiting mite *Atomus* appears negligible in its effect when canes are tall and massed in growth; the field determined figure 4% is considered adequate for all conditions during September.

[5] These F4 figures were determined over the entire period of each month; see footnote 2, p. 65.

[6] See p. 63.

Before proceeding with any analysis or comparison of the above examples, some essential facts in the control of *Diatraea* in cane must be made clear and salient points brought into clear relief.

(a) In the first place, the cane crop takes from 14 to 17 months from springing to reaping, during the whole of which period in Barbados, it is open to infestation; in consequence *Diatraea* is never without adequate supplies of its host plant, and the host plant is seldom without actual or potential damage from *Diatraea.*

(b) *Permanent* damage to canes occurs over a minimum period of 9 months and a possible period of 12 months out of the above period. The damage to the crop which is assessed at reaping time, is the accumulation of this damage.

(c) In Barbados, maximum and vital cane growth begins from late May or early June onwards, with the commencement of regular summer rainfall, and at the same time, the normal curve of *Diatraea* population rises rapidly during the ensuing 5 to 6 months reaching its peak around September. This period is referred to in this paper as the critical period of cane growth and borer infestation.

(d) Mortality factors, whether general or individual, are correlated with climatic and cane growth conditions and possibly with cane variety and are by no means constant. It is possible for very considerable fluctuations in mortality factors to occur at any period. As will be shown, the end result of total real mortality may not be largely affected by these fluctuations but as has been pointed out, apparently small fluctuations in total real mortality may have very considerable effects on total accumulated damage.

(e) It is therefore necessary to understand that in each example given in Table I, the mortality factors, though adequately determined, are considered by the writer as applying only to the *Diatraea* population at the period during which the values of the factors were determined, and that both *Diatraea* egg population and mortality factor values may subsequently vary considerably in that particular area. Wherever possible therefore the calendar month is taken as the minimum period over which average values of mortality factors can satisfactorily be determined, and as a maximum period over which the interaction of *Diatraea* population and average mortality factors can be worked out to indicate the end results which can reasonably be expected to result from such interaction.

It is of little use to take restricted field observations on mortality factors over a limited period and quite wrong to consider that the results or deductions obtained therefrom apply continuously or to any other period of the year, as is stated or implied in current contributions (1) to the control of *D. saccharalis* in cane.

(f) It must be recognised that in the above calculations, a total real mortality of 98% arrests the annual upward curve of population described in the 3rd section (c) above, only at the point at which 98% is reached and for the period only at which this figure of total real mortality is maintained.

Further, although the *Diatraea* population then remains stable, the damage to canes does not but still accumulates steadily, though at a much slower rate.

As the real mortality total sinks below 98%, *Diatraea* population increases and borer damage increases with a rapidity which increases with the descent below 98%; conversely, as real mortality exceeds 98% even by a small amount *Diatraea* population diminishes, and borer damage decreases until, under optimum conditions of an increase of 2% over 98%, *Diatraea* is exterminated and borer damage becomes nil. It would appear therefore that comparatively small fluctuations in total real mortality around 98% or say between 90% and 100% will have very marked effects on the total accumulated damage assessed at the reaping period of each crop. In figurative language, it can be said that relatively small movements on either side of the fulcrum of a recording arm 10 to 12 months long, will cause big variations in the records made.

The complexity of the *Diatraea* problem has necessitated the foregoing definition of facts and of probabilities, which show that the analyses in Table I are based on factors which have been determined with as great care and accuracy as the nature of the work permits, or when not experimentally determined, have been assessed on the basis of considerable field experience.

Where comparisons are made, they are based on results, or probable results, for the same period of the year, and are therefore legitimately comparable.

Where forecasts are made, they are considered as applying to the stated period of the year only, their extension beyond that period depending on the stability of mortality factors.

Finally, the examples are all confined to the critical period of cane growth and rising *Diatraea* population when borer damage becomes permanent and cumulative.

A further digression must be made to place clearly on record the manner and extent of parasite colonisation in Barbados, and method of cane planting, so that the relation of numbers of parasites per acre to cane shoots per acre may be made more comprehensible to those who visualise canefields in the light of growth conditions or cultivation practices, prevalent elsewhere, but not applicable to Barbados.

In Barbados, cane is planted on the cane hole system, not in a continuous furrow system, and the number of cane holes, each containing one stool, varies with the locality and rainfall for that locality. Thus, in some areas, canes are planted at the rate of 1,210 stools per acre; in others 1,452 and in others 1,742 stools per acre. At the period of *maximum* tiller or shoot production, a stool would contain (for that period) an *average* of 20 shoots; the period of maximum tiller production is usually in July, but does not necessarily occur in the same month of each year. From this average tiller or shoot production, an average of 13 mature canes is general. If, therefore, it is considered that an average field contains 1,500 stools of cane per acre which reach a maximum average of 20 shoots per stool around July, and a final maximum production of 13 canes per stool by November, and that the average field in Barbados is between 5 and 6 acres in extent, an adequate idea of a canefield in Barbados will be reached. Obviously, however, in the stages of early cane growth when there are two or three shoots per stool in January, five to seven as an average in February, seven to nine in March, eleven to fourteen in April, fourteen to seventeen in May, fourteen to seventeen in June, seventeen to twenty-three in July, etc., the number of cane shoots per acre varies: so also does the number of *Diatraea* eggs per acre, and the natural parasitism by *Trichogramma*.

When considering the artificial colonisation of *Trichogramma* in fields as above, it would appear necessary to show what relation a liberation of 130 million parasites over an average period of about 26 weeks (March to September), bears in liberations per acre to natural parasitism per acre for these periods.

In the first place, parasites are fetched by the planters themselves from the central breeding station, and the slips of parasitised eggs placed out in fields by plantation labour, so that the parasites hatch from these slips a few hours after being placed in the fields.

Each plantation is, at first, given each week enough slips of parasitised eggs to colonise one quarter of the plant cane acreage of that plantation, with instructions to distribute 12 slips in each acre of cane. If a plantation comes in regularly for supplies, then obviously, *each acre of the estate is colonised once during each month that parasites are available for distribution.* This is the theory: in practice, plantations do not send in regularly so that some take less, leaving a balance which is given to those that do send in that week, and who therefore obtain and distribute more than the above quota. There is however not the slightest difficulty in getting each week's production distributed throughout the canefields of the Island, though it is obviously expecting too much for the distribution

to be absolutely even week by week. As ratoon canes spring and produce fields suitable for colonisation, the quota for each plantation is increased to include ratoon as well as plant cane acreage, as described more fully later on.

The next point is, at what rate is this colonisation of each acre once a month, made; and what relation does the number added per acre bear to the natural field population?

The colonisation rate in 1933 was:—February, 936 per acre (limited distribution) March 1,644 (full distribution from now to end August); April 1,296; May 796; June 864; July 840; August 996; September 912 (limited distribution). That is, during each of the stated months, each acre of plant cane (and later on ratoon canes also) could receive one such colonisation: actually, as stated, some plantations could not fetch that quota regularly, leaving more for others, and some plantations would concentrate liberations in fields which, from present signs or past experience were likely to be badly infested with *Diatraea*.

To give figures for average plantations, one plantation having 275 acres of plant and ratoon cane, distributed 878,000 parasites over a period of 7 months. Now all this acreage was not at the right stage for *Trichogramma* colonisation at one time, because plant canes are ready much before ratoon canes, and ratoon canes come in at different stages (according to date of last reaping.) Thus, for the above estate, there were 170 acres of plant cane ready for colonisation in February: 170 acres in March: then ratoon canes enter the picture and in April 185 acres were suitable for colonisation; 220 in May; 255 in June; 275 in July and 275 in August; but always the 170 acres of plant canes took precedence for distribution on account of growth, and on account of the invariably greater infestation in plant compared with ratoon canes. Another example of an average colonisation is furnished by an estate or plantation, having 73 acres of plant cane, and 137 of ratoons; this estate had colonisation acreages of 73, 73, 100, 130, 165, 195, 210, from February to August, inclusive; and distributed altogether 689,600 parasites in 6½ months. Some estates have a greater proportion of plant cane than the above and some have less; also some estates distribute parasites more regularly, (that is, would distribute a greater total for the same acreage) than the above, and others less.

One can only return to the basic provision made for parasite distribution and say that each estate was entitled to treat one quarter of its available acreage each week, at the rate per acre given above, and that each month an increasing acreage was treated. It is obvious, of course, that even 130 million parasites, distributed as above, is not fully sufficient for complete control, even though, as shown, it is not necessary to treat the entire cane acreage of the Island; the point is, that the correct timing and judicious distribution of its quota by each plantation has achieved a very satisfactory measure of control over *D. saccharalis* which is shown by practical field results, and borne out in theory by the mathematical analysis based on field data given later.

To say that this system of colonisation represents an addition of seven parasites per acre per day as has been published by one critic (2) or even to take the present total of 130 million parasites distributed over the average period of

26 weeks throughout 35,000 to 36,000 acres of plant *and ratoon* canes as equivalent to adding 143 parasites per acre per week, is on the same plane as to say that the total lead arsenate applied to a commercial apple orchard in each annual codling moth spraying programme (limited to a definite period) is equivalent to, say .00 x grains of lead arsenate per tree or per branch per day; neither calculation would give a figure which looks at all impressive or useful, and neither would accurately express the actual conditions which give an economic or commercial control.

To return to facts, it is possible to compare definitely the numbers of parasites liberated per acre per month in 1933, with the natural or normal population of *Trichogramma* per acre per month in an uncolonised area in that year.

In 1933, a systematic bi-weekly examination was made throughout the year of eggs deposited, and of natural parasitism, in 12 plots each of 40 cane stools and from these results (published in Agric. Journal, Dept. Sci. and Agric. Vol. 2 No. 4), the average number of eggs per acre per month, average parasitism per month, and therefore total average number of parasites emerging per acre each month in an uncolonised area are available. These figures can be compared with the parasites added per acre per month, on the basis of *one colonisation only per acre per month* in the following table. (Eggs per acre are as given in Table XI *loc. cit.*, with an addition of 15% for field errors).

TABLE II.

Month	Average *Diatraea* eggs per acre	Average natural *Trichogramma* percentage	Number of natural *Trichogramma* per acre per month	Number of *Trichogramma* added per acre per month
February	16,236	8.0	1,299	936
March	27,605	6.1	1,684	1,644
April	23,120	11.5	2,660	1,296
May	23,412	31.9	7,465	796
June	8,608	32.9	2,832	864
July	2,424	18.75	454	840
August	2,769	32.8	908	996
September	6,079	52.0	3,161	912

If ever the production of *Trichogramma* in Barbados is increased beyond 130 millions, or if increased production is obtained in any one month, the numbers colonised per acre can be increased at any time desired by increasing the number of parasitised eggs on the card slips or sections distributed in the fields. As it is the numbers added per acre per month bear a satisfactory mathematical relation in most months to the natural emergences of *Trichogramma*, even on the basis of one colonisation only per acre per month, and at the rate of 130 millions per "season". The statement that "the normal population of *Trichogramma* per

acre within a given brief period is extraordinarily high—up to nearly three million'' (5) is entirely outside the writer's experience and does not occur in Barbados during the period covered by colonisation of *Trichogramma.*

Attention has also been called elsewhere (9) to the fact that the figures of *Diatraea* eggs per acre per month given above and obtained from bi-weekly counts in 12 (diminishing by one each month) plots of forty cane stools each, when 1,742 stools represent 1 acre, are very much smaller than figures given in (1) obtained in Antigua by counts of eggs on 5 or 10 stools, when 2,500 stools are stated as representing one acre, or even counts of eggs on 25 stools when 3,500 stools represent one acre.

Even allowing for the difference in the number of stools per acre, it is probable that eventually the total *maximum* number of cane shoots per acre approaches greater equality in both cases than one would expect; hence if 327,810 eggs can be found per acre on young cane in February in Antigua and 286,500 in young cane in April, and 1,566,000 per acre in December in ripe cane, infestation by *Diatraea* must be very much more severe now in Antigua than it is at the present time in Barbados; which is an additional indication that control over this pest is being obtained in Barbados.

The figures given in Table II have been obtained by continuous field work, adequately checked, and on as large a scale as can be handled with accuracy, and give some idea of the relation between numbers added by parasite colonisation and those present by natural emergences in 1933, though it must be pointed out again that on some estates more than one colonisation would be made in any one field in some months, particularly in plant cane during the early months, so that some areas get more than the stated numbers per acre: and some get less, or, in rare cases, none. Also, provision is made for each acre to be colonised *once each month* so that, even if missed out entirely during some months, each acre should get, at least, one or two colonisations during the entire period of parasite distribution. Finally it must be remembered that an early colonisation of a few hundred *Trichogramma* per acre, in the absence of a high natural *Trichogramma* population, may, if it coincides with a considerable deposition of *Diatraea* eggs, produce a few thousand additional *Trichogramma* seven or eight days later in the same month, which is equivalent to a second colonisation. This is why successive colonisations are made, and why field parasitism by *Trichogramma* may increase apparently out of proportion to the numbers colonised.

It should be clear therefore that in Barbados (a) colonisation may range from a total of 8,284 *Trichogramma* per acre if colonised once each month to a minimum of 796 per acre if colonised once only during the colonisation period (b) that some fields are not colonised at all, either because they are late ratoons, or because they are considered by the plantation management not to require colonisation, and that therefore the entire 35,000 to 36,000 of cane acreage in Barbados neither needs nor receives, colonisation, (c) owing to the small size of fields in Barbados, and the absence of really serious natural obstacles, there is always a wind drift and distribution of *Trichogramma* which gives at least partial protection to any non-colonised field or area.

This survey of cane field conditions, and method of colonisation of *Trichogramma* in Barbados, should make clear the condition of cane growth, size of fields, number of shoots per acre, and relation of method of colonisation, and of numbers distributed per acre to plant and ratoon canes.

These various statements of conditions, and definition of terms and of methods may interrupt the continuity of this paper, but are considered necessary in order that the conclusions which are reached in this, and in preceding papers on this subject, and results which will be published later on in this Journal series, may be clearer and more intelligible in view of the direct statement (1) that "The conclusion of various examinations made (in Antigua) to determine the "natural *Trichogramma* population of representative cane-fields of different "categories produced direct evidence of the ineffectiveness of *Trichogramma* as a "means for controlling sugar cane moth borers." The positiveness of this statement based on non-colonised conditions undoubtedly calls for full statements of facts and evidence relating to colonisation, and which the writer edeavours to give for the stage now reached in this work.

Discussion of Complexes for which Definite Mortality Values have been Determined.

In Table I, there are four complexes only for which actual mortality values have been determined, and they are Ia and Ie for June, and IIa and IIe for September. In these two complexes, only F2 differs in value, and the difference is that caused by mass colonisation of *Trichogramma*.

Thus, in June the total real mortality with mortality factors as in Ia, Table I, when *Trichogramma* is not colonised is 95.41%; the total under the same conditions, when *Trichogramma* is colonised at the rate of 130 millions for that portion of the year inclusive of June and September, is 97.95%. Mass colonisation of *Trichogramma* in 1933 therefore resulted in a decrease of 2.54 effective *Diatraea* larvae per 100 *Diatraea* eggs laid during the June period, compared with conditions prior to *Trichogramma* colonisations. This means that 2.54 fewer larvae bore into, and complete their development per 100 *Diatraea* eggs laid in June, and that 1.27 *fewer* female moths escape per 100 eggs (or 5 per 400 eggs) to increase the *Diatraea* population in that month.

The corresponding complex in September shows that when *Trichogramma* is not colonised, then total real mortality is 67.74% as in IIa, the difference compared with June being due to the much smaller final larval mortality; when *Trichogramma* is colonised at the rate of 130 million for that critical period of the year, the total real mortality is 93.27% as in IIe. The increase in real mortality in this case, due to colonisation is 25.53% or expressed as above, 25.5 *fewer* larvae bore into and develop fully in canes and 12.75 fewer female moths escape for each 100 *Diatraea* eggs laid in this period.

These decreases in effective larvae and of female moths materialising from each 100 eggs deposited in June and in September, plus the decreases in the remaining months of *Trichogramma* colonisation, namely, March, April, May, July,

August and sometimes part of October, are *quite capable of causing the large decrease in accumulated borer damage to cane which has been shown to occur in five successive crops reaped in Barbados since the commencement of Trichogramma colonisation.**

The extent of this diminution in damage has already been published from time to time (10) and full results of annual crop damage based on adequate factory and field determinations will be published when the sixth crop grown under *Trichogramma* control has been reaped in 1934.

It will be noted that the field value determined for early larval mortality (F4) is low in September which is in accordance with the writer's observations during years of field work, that *Diatraea* larvae penetrate canes and survive far more effectively during the June to October period of cane growth which is the critical period mentioned elsewhere. It is, moreover, in accordance with the reduction in damage which has been recorded and claimed as resulting from the mass colonisation of *Trichogramma* in Barbados, and which results, as shown in Table I, in a most definite increase in the percentage of total real mortality.

. The results which would follow were a minimum figure of 97% early larval mortality to be actual fact in place of 16% which is the field determination of early larval mortality for September, will be examined in due course.

Discussion of Complexes for which Mortality Factors are Introduced or Changed in Value.

The foregoing discussions have shown the effectiveness of increasing *Trichogramma* parasitism by extensive colonisation during the critical period of cane growth, and have demonstrated a definite agreement between the field results obtained so far in Barbados and the mathematical results shown to follow increases in F2 due to *Trichogramma* colonisation.

(A) *Absence of Colonised Trichogramma and Presence of Effectively Established Larval Parasites.*

Consideration must now be given to the conditions which would be produced were mass colonisation with *Trichogramma* inoperative owing to its never having been started, or to its discontinuance, and were an average F5 value of 35% (stated in current literature to be operative) due to *Lixophaga* (or *Paratheresia*) introduced into the complex.

Conditions would then be as in Ib for June and IIb for September, the resulting real mortalities being 97.02% and 79.01% respectively. This means an increase of 1.67% in real mortality in June, and an increase of 11.27% in

* This decrease is reflected in increased sugar crop during all the years of *Trichogramma* colonisation. These years have also been years of much better rainfall, and this factor, together with more scientific manuring, improved cane varieties, control of cane root borer and brown hardback, and improvements in factories, have all contributed to these increased crops. It is, however, within reason to suggest that a part of the increase of 32,000 tons of sugar obtained in 1933 alone over average conditions prior to 1928, is due to the proved reduction in moth borer damage.

September (i.e. presuming an average of 35% larval parasitism to be still operative in September).

These increases can be compared with the corresponding increase of 2.54% in June and 25.53% in September which result from mass colonisation of *Trichogramma* as obtaining in 1933. It would appear from such comparison that extensive mass colonisation of *Trichogramma* is more effective than a comparable parasitism by a mature larval parasite.

A still more direct comparison can be made by considering the increase in egg parasitism due to mass colonisation of *Trichogramma* to be 35% instead of 37% in June 1933 (i.e. substituting 68% for 70% as F2 in Ie). The result will be a total real mortality of 97.81%, or an increase of 2.4% over pre-*Trichogramma* conditions as in Ia, where total real mortality is 95.41%.

When a 35% F5 due to a mature larval parasite or parasites is substituted for the above increase of 35% in egg parasitism, we get, as stated, a total real mortality of 97.02% (Ib), or an increase of 1.61% over the standard figure of 95.41%.

The difference between these two parallel complexes in June is a .79% higher real mortality in favour of mass colonisation by *Trichogramma*, at the rate stated for 1933.

That is to say, under otherwise equal conditions, during the month of June a 35% increase from normal in parasitism by *Trichogramma* will allow 8 fewer larvae per 1000 *Diatraea* eggs laid to bore into and develop fully in canes, and will allow 4 fewer female moths per 1000 eggs, to escape and increase infestation, than would a 35% increase over normal larval parasitism in Barbados by a mature larval parasite.

The cumulative value of this difference per 1000 eggs in June plus greater differences in the following months of *Trichogramma* colonisation (plus some benefit in the preceding months of colonisation), should produce a diminution in damage and an increase in tonnage of sugar far in excess in its value to the annual cost in Barbados of the routine work of rearing and distributing *Trichogramma*.

Colonisation of *Trichogramma* therefore would appear from this mathematical analysis to give financial as well as theoretical results which are superior to the establishment in Barbados, if such can be accomplished, of a larval parasite.

This does not in the least mean that larval parasites of *Diatraea* are without value either in Barbados or elsewhere; on the contrary it will be shown later that there is real value in introducing a mature larval parasite in *conjunction with* present mass colonisation. The introduction, therefore, of *Lixophaga diatraea* and *Paratheresia claripalpis* plus laboratory assistance towards establishment, is contemplated for 1934 in Barbados.

With regard to the comparison just drawn the writer is aware that figures in excess of 35% parasitism are claimed for some larval parasites of *Diatraea* but

so are figures higher than 70% for June and 90% for September obtained in *Trichogramma* work: the comparisons have been based as equitably as possible on average parasitisms.

(B.) *Continuance of Colonisation of Trichogramma and Addition of Effectively Established Larval Parasites.*

The next complex to be considered is that projected for Barbados, namely the establishment if possible, of a larval parasite of *Diatraea* such as *Lixophaga* or *Paratheresia* or both. Assuming the permanent establishment of *Lixophaga* or *Paratheresia* at an effective average parasitism of 35% we should get the complex If. in June and IIf. in September. The total real mortalities then become 98.63% and 95.62% respectively. That is to say, the addition to conditions as in 1933 of a 35% mature larval mortality in June, will raise the real mortality from the existing 97.95% (Ie) to 98.63%, and in September it will raise it from 93.27% (IIe) to 95.62%. The difference thus being 0.68% increase in real mortality in June and 2.35% increase in September.

It will be seen from the above that, in view of the fact that 98.0% total real mortality means a cessation of *increase* in pest populations, (though as explained elsewhere, it does not mean a cessation of damage to cane), the complex Ie. which is brought about in colonised plots in June approaches very near to but does not reach this stability of population: the increase of .68% in the real mortality, due to the establishment of a 35% larval parasitism in conjunction with colonised *Trichogramma* parasitism does however produce a state of affairs in which pest population *decreases* instead of being not quite at the no increase stage and is therefore of very considerable value. In September, although the increase in real mortality, due to added larval parasitism, is greater, it would still not arrest the increase in pest population, but would nevertheless bring conditions perceptibly nearer to this desired condition.

The writer considers, therefore, that small as the above increases are, their proximity to the critical 98.0% real mortality during the critical period of cane growth and borer injury, renders them well worth while. In the interest therefore of the control of *D. saccharalis* in cane, every effort will be made in 1934 to establish either or both of these parasites in Barbados.

(C.) *The Substitution of a 97% early Larval Mortality for the Determined Larval Mortalities used in the Preceding Calculations.*

The preceding discussions have involved the analysis and comparison of two complexes which previously existed, and two which now exist in Barbados; two which might be possible in Barbados (similar complexes are now being built up in Antigua and St. Lucia); and two complexes which it is hoped to build up in Barbados next year. These eight complexes must now be examined in the light of a supposed *average* of 97% early larval mortality, and are shown as Ic, Id, Ig, and Ih, for June, and IIc, IId, IIg and IIh for September.

Actually, however, the only ones which need be considered and compared are Ig and IIg which are complexes *which exist now in Barbados if the F4 value*

of 97% average is correct, and Ih and IIh which will exist next year if larval parasite establishment is successful in Barbados.

Examination of the possibly existing complexes Ig and IIg, show that total real mortality would, under such conditions, be 99.41% in June and 99.75% in September.

This could have no meaning other than that from June onwards (and probably before), *Diatraea* population not only does not increase in normal fashion, but that it declines to the point of extinction.

Under these conditions the control of *D. saccharalis* in Barbados would be far more extensive and absolute than the writer has knowledge of at present. A sweeping control such as indicated by these figures may of course be revealed when the 1934 crop is reaped, thus showing that the high figure of 97% early larval mortality has been operative; the writer however does not anticipate this result and will be content with any reduction made possible by the lower and varying early larval mortalities as determined by field experiments in 1933.

It would appear, indeed, that early larval mortality is the dominant factor in any biological measures for the control of *D. saccharalis* in sugar cane because (1) it is a numerically large factor (2) it fluctuates considerably (3) it is dependent upon conditions which place it beyond human control. Thus it may, by its fluctuations both regional and seasonal upset any predictions or reasonable expectations as to the final amount of borer damage to be found at reaping time.

Though a variable, and at times very large general larval mortality is therefore bound to cause fluctuations in final accumulated damage due to *Diatraea,* it does not prevent the control brought about by colonisation of *Trichogramma* from being effective. Variations in *Diatraea* infestation and in borer damage will obviously occur whether *Trichogramma* is colonised or not, but *with* effective colonisation these fluctuations occur on a much smaller scale, and damage is maintained at a minimum.

The conditions which would exist in Ih and IIh, were a 35% larval parasitism present, show very little increase in the above figures, but even these increases would bring absolute control perceptibly nearer.

CONCLUSION.

The foregoing mathematical analysis of conditions as they now are in Barbados, and comparison with the analysis of conditions as they would be without mass colonisation of *Trichogramma,* together with analysis of conditions as they might be were a mortality factor such as a well established mature larval parasitism introduced, or were an existing factor such as early larval mortality greatly increased in value, prove the following points.

1. The annual increasing of average parasitism of *Diatraea* eggs through mass colonisation of *Trichogramma* produces mathematical results in increased real mortality of *Diatraea* which are in agreement with and can

undoubtedly cause, the annual decrease in accumulated borer damage and annual rise in tonnage of sugar which have been proved in Barbados over a period of five years*

2. The substitution of larval parasitism of *Diatraea* for increased egg parasitism due to mass colonised *Trichogramma* is shown mathematically to produce a definitely lower total real mortality than that now obtained by mass colonisation of *Trichogramma.* Mathematical comparisons show that a 35% average increase above normal in parasitism by *Trichogramma* produces a greater total real mortality than would the substitution of an average of 35% increase above normal in larval parasitism in Barbados; all other mortality factors remaining equal. Further the cumulative effect of this difference can reasonably be considered sufficiently large to produce an economic return far in excess of the annual cost to Barbados of mass colonisation of *Trichogramma.*

3. The combination of the existing control obtained by mass colonised *Trichogramma* with introduced and permanently and effectively established larval parasites, would produce a satisfactory increase in total real mortality and therefore of control. For this reason both *Lixophaga* and *Paratheresia* are being introduced into Barbados, and will be fostered by laboratory methods in order that they shall have the maximum chance to become permanently established.

4. The existence of an average of 97% early larval mortality would, under existing conditions in Barbados, result in virtual extermination of *D. saccharalis.* This does not at present appear to be the case, and as experimental determination of the various mortality factors has shown that early larval mortality during the critical period of cane growth in Barbados fluctuates considerably, and reaches quite low average figures for some months, which figures produce real mortality totals more in keeping with field results, it is concluded that a continuous average of 97% early larval mortality does not exist.

   Early larval mortalities of 90% and over occur frequently in the non-critical months of cane growth, and most probably *occasionally* during the main, or critical period of growth.

   When such high larval mortality occurs in the latter period, the mathematical analysis of such conditions shows that any rise in *Diatraea* population is stopped and borer damage to canes reduced to a minimum; or that both population and damage are reduced to nearly zero for that period.

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* The figures showing the annual increase in field parasitism of *Diatraea* eggs with annual increase in *Trichogramma* colonisation, and their correlation with annual decrease in borer damage, increase in mill juice purities, and increase in sugar tonnages, will be published in full in 1934 when the results of the sixth crop reaped and analysed are available.

This would be one explanation of the very variable infestation which is now increasingly found in fields of cane in Barbados; the proved occurrence of over 90% and up to 100% of parasitism by *Trichogramma* would also produce similar results.

Early larval mortality would, therefore, appear to be the dominant factor in any biological measure for the control of *D. saccharalis* in sugar cane, because (1) it is a numerically large factor (2) it fluctuates considerably (3) it is uncontrollable. Thus it may, by its fluctuations, both regional and seasonal, upset any predictions or reasonable expectations as to the final amount of damage caused by *D. saccharalis*.

Though a variable, and at times very large general larval mortality is therefore bound to cause fluctuations in final accumulated damage due to *Diatraea*, it does not prevent the control brought about by colonisation of *Trichogramma* from being effective. Variations in *Diatraea* infestation and in borer damage will obviously occur whether *Trichogramma* is colonised or not, but *with* effective colonisation these fluctuations occur on a much smaller scale, and damage is maintained at a minimum.

5 A resumé is given of colonisation methods and conditions of cane growth and of cane planting in Barbados which should make clear the general conditions under which economic control over *D. saccharalis* has been obtained, and also make clear the relation between numbers of parasites colonised per acre in 1933 and the number of *Trichogramma* present naturally per acre month by month.

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